NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

BASELINE ESTABLISHMENT USING VIRTUAL ENVIRONMENT TRAUMATIC BRAIN INJURY SCREEN (VETS)

by

Casey G. DeMunck

June 2015

Thesis Advisor:	Lee Sciarini
Second Reader:	Joseph Sullivan

This thesis was performed at the MOVES Institute

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704–0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	06-19-2015	Master's Thesis 07-01-2013 to 06-19-2015

4. TITLE AND SUBTITLE

BASELINE ESTABLISHMENT USING VIRTUAL ENVIRONMENT TRAUMATIC BRAIN INJURY SCREEN (VETS)

5. FUNDING NUMBERS

6. AUTHOR(S)

Casey G. DeMunck

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Postgraduate School
Monterey, CA 93943

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

N/A

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

The views expressed in this document are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol Number: NPS.2015.0030-IR-EP7-A.

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

The Virtual Environment Traumatic Brain Injury Screen (VETS) prototype was designed to enable the assessment of mild traumatic brain injury (mTBI). This research aims to establish baseline data for balance as an indicator for mTBI and determine reliability of the VETS device. Objectives of this research were to examine the within-session and between-day performance of four balance-based indictors of mTBI with a healthy military population. Fifteen healthy individuals participated in two sessions, separated by a week, where they were tested under six conditions for three trials each. Balance data were recorded by the VETS system using a Wii Balance Board with participants in a quiet stance. In-session performance was examined using a paired-samples t-test. A repeated-measures ANOVA was used to individually examine differences between trials across both sessions. A final repeated-measures ANOVA was used to explore all trials across both sessions. Results revealed that the participant performance remained constant or improved across trials and sessions suggesting that a practice effect may have occurred in some conditions. These results suggest that the VETS device reliably measures balance as an indicator of mTBI. Further, these results establish a baseline data set, which may be useful in comparing concussed individuals.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Concussion, mild traumatic brain injury (mTBI), traumatic brain injury (TBI), balance, Sensory Organization Test, Balance Error Scoring System, center of pressure, Virtual Reality, diagnosis, commercial off-the-shelf, Wii Balance Board, Virtual Environment	93
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2–89)
Prescribed by ANSI Std. 239–18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

BASELINE ESTABLISHMENT USING VIRTUAL ENVIRONMENT TRAUMATIC BRAIN INJURY SCREEN (VETS)

Casey G. DeMunck
Major, United States Marine Corps
B.S., United States Naval Academy, 2003

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MODELING, VIRTUAL ENVIRONMENTS, AND SIMULATION

from the

NAVAL POSTGRADUATE SCHOOL
June 2015

Author: Casey G. DeMunck

Approved by: Lee Sciarini
Thesis Advisor

Joseph Sullivan
Second Reader

Christian Darken
Chair, MOVES Academic Committee

Peter J. Denning
Chair, Department of Computer Science

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The Virtual Environment Traumatic Brain Injury Screen (VETS) prototype was designed to enable the assessment of mild traumatic brain injury (mTBI). This research aims to establish baseline data for balance as an indicator for mTBI and determine reliability of the VETS device. Objectives of this research were to examine the within-session and between-day performance of four balance-based indictors of mTBI with a healthy military population. Fifteen healthy individuals participated in two sessions, separated by a week, where they were tested under six conditions for three trials each. Balance data were recorded by the VETS system using a Wii Balance Board with participants in a quiet stance. In-session performance was examined using a paired-samples t-test. A repeated-measures ANOVA was used to individually examine differences between trials across both sessions. A final repeated-measures ANOVA was used to explore all trials across both sessions. Results revealed that the participant performance remained constant or improved across trials and sessions suggesting that a practice effect may have occurred in some conditions. These results suggest that the VETS device reliably measures balance as an indicator of mTBI. Further, these results establish a baseline data set, which may be useful in comparing concussed individuals.

THIS PAGE INTENTIONALLY LEFT BLANK

Table of Contents

List of Figures

THIS PAGE INTENTIONALLY LEFT BLANK

List of Tables

List of Acronyms and Abbreviations

ACH	Advanced Combat Helmet
ANOVA	analysis of variance
AP	anterior posterior
BESS	Balance Error Scoring System
COP	center of pressure
COTS	commercial off-the-shelf
CT	computed tomography
CTSIB	Clinical Test for Sensory Integration of Balance
DOD	Department of Defense
FDA	Food and Drug Administration
GCS	Glasgow Coma Scale
GUI	graphic user interface
HMMWV	Highly Mobile Multipurpose Wheeled Vehicle
HSI	Human Systems Integration
ICU	Intensive Care Unit
IED	improvised explosive device
IRB	institutional review board
JIEDDO	Joint Improvised Explosive Device Defeat Organization
LOC	loss of consciousness
LVS	Logistics Vehicle System

LVSR Logistics Vehicle System Replacement

LWH Lightweight Helmet

MACE Military Acute Concussion Evaluation

MICH Modular Integrated Communications Helmet

ML medial lateral

MRAP Mine Resistant Ambush Protected

MRI magnetic resonance imaging

mTBI mild traumatic brain injury

MTV Medium Tactical Vehicle

MTVR Medium Tactical Vehicle Replacement

NFL National Football League

NIJ National Institute of Justice

NPS Naval Postgraduate School

OEF Operation Enduring Freedom

OIF Operation Iraq Freedom

PASGT Personnel Armor System for Ground Troops

PTSD Post Traumatic Stress Disorder

RMS root mean square

SAC Standardized Assessment of Concussion

SOCOM Special Operations Command

SOT sensory organization test

SPSS	Statistical Package for the Social Sciences
SSQ	Simulator Sickness Questionnaire
TBI	traumatic brain injury
TTP	tactics, techniques, and procedures
U.S.	United States
USAF	United States Air Force
USA	United States Army
USMC	United States Marine Corps
USN	United States Navy
VE	virtual environment
VETS	Virtual Environment Traumatic Brain Injury Screen
WBB	Wii Balance Board

THIS PAGE INTENTIONALLY LEFT BLANK

Acknowledgments

The author would like to thank Lieutenant Jay Haran, USN, for providing the idea of creating the VETS device, for providing the hardware and software necessary to conduct this study, and for advice throughout the execution of this study.

THIS PAGE INTENTIONALLY LEFT BLANK

CHAPTER 1:
Introduction

1.1 Overview

The condition traumatic brain injury (TBI) is a temporary or permanent neurological dysfunction caused by an external force on the body. TBI can also result from the body being shaken violently or being in an accelerated state and stops suddenly. In the military domain, TBI typically results from an individual being exposed to the effects of explosions. Effects can be direct, as when the shock wave of an explosion passes through the skull, or indirect, as when an individual is thrown and his or her head impacts another object. The injury can be "open," as a visible injury to the head, or "closed," as with internal injury of the brain with no visible external injury. TBI is classified into three levels of severity: mild traumatic brain injury (mTBI), moderate, and severe. This thesis focuses on closed mTBI.

Compared to previous conflicts, Iraq and Afghanistan have resulted in increased explosive-related injuries to the head and neck. Injuries to the head and neck have increased to 30 percent of injuries sustained by military personnel, up from 21 percent during World War II [1]. The injury mechanism during current conflicts is predominately caused by explosions, 81 percent of injuries, as opposed to gunshot related injuries, 19 percent of injuries. Of diagnosed TBI in military personnel, mTBI comprises 77 percent of the cases [2], [3].

During the final stages of conflict in Operation Enduring Freedom (OEF)/Operation Iraq Freedom (OIF), there was a mandatory minimum 24-hour rest period if military personnel are exposed to the effects of an explosion, regardless of whether the individual is showing signs of mTBI [4]. To work, this system relies heavily on self-reporting, evaluation by deployed medical personnel, and leaders educated in the effects of mTBI. In the distributed and remote nature of deployments, such as to Afghanistan, medical personnel may not be present to prescribe bed rest for 24–96 hours. Due to manpower constraints, it may not be tactically feasible to place all personnel who felt the effects of an explosion on bed rest for that time frame. For example, if an explosion occurs next to a mine-resistant vehicle carrying eleven people, under the current standard all eleven should be placed on bed rest

at the earliest possible time, even though only one may be showing symptoms of mTBI.

Symptoms of mTBI can manifest themselves in three different categories: alterations of the somatic system, cognitive ability, and psychological effects. Impacts to the somatic system can result in headaches, dizziness, and degradation of the senses [5]. Cognitive effects express themselves as memory loss, inability to pay attention, or difficulty with common tasks such as speech. Psychological repercussions include changes to personality, depression, anxiety and, in extreme cases, suicidal tendencies. Additionally, mTBI is also linked with Post Traumatic Stress Disorder (PTSD) due to the often traumatic nature of mTBI producing events and an evaluation for PTSD should be considered if an individual is diagnosed with a TBI [5].

Immediate treatment of mTBI centers on reducing the risk of another concussion in the days after the first event. If an individual receives ample rest and treatment of symptoms shortly after a mTBI producing event, his or her chances of long-term neurological dysfunction are greatly reduced [5]. If, however, an individual is exposed to additional mTBI-producing events after the first incident, his or her chances of long-term adverse effects are increased [6].

1.2 Background

Screening methods for mTBI range from biomarkers in the bloodstream to cranial ultra sounds [7]. These procedures require medical facilities and trained personnel to administer them. One screening method is to test balance. Mild TBI has an adverse effect on the vestibular system and thus compromises the individual's ability to balance. Typically, this is not visible in a person affected by mTBI due to the body's ability to compensate for a degraded vestibular system by using visual cues and the somatic system to determine the individual's orientation relative to the ground. If a person affected by mTBI stands on an unstable surface, such as foam, which isolates the somatic system, and is told to close his or her eyes, he or she will be unable to balance or find it extremely difficult to do so, as the injured vestibular system is not functioning properly [8]. This is a prime indicator of mTBI but does not serve as a diagnosis [9].

The VETS device [10] isolates the vestibular system as a way to screen for potential mTBI. By using a virtual environment, visual cues to the user can be controlled to remove reliance

on ocular input. A Wii Balance Board (WBB) is used as an input device to measure how well the user is balancing. Foam can be added on top of the board to reduce the somatic system's ability to compensate for a degraded vestibular system. This device has the potential to be used as a low-cost screening tool in a deployed environment in order to target mTBI treatment for those who need it most.

1.3 Objectives

This thesis studies human subjects using the Virtual Environment Traumatic Brain Injury Screen (VETS) device [10] to collect baseline data on a healthy military demographic. The goal of this study will be to establish a norm for which individuals with possible mTBI symptoms can be screened. To this date, a healthy military population baseline has not been established using the VETS device. Additionally, the feasibility of the VETS device as a low-cost screening tool utilized in a deployed environment will be evaluated.

If a healthy military population baseline for balance can be established using the VETS device, then the device can potentially be used as a low-cost portable screening tool for concussion injuries. This can provide the Department of Defense (DOD) with an effective tool for detecting potential mTBI far forward in a deployed environment, which will greatly enhance an affected individual's chances of a speedy recovery and potentially reduce incidence of subsequent concussions.

1.4 Scope and Limitations

If we think of a TBI producing event, an acute injury, as being at the middle of a spectrum, there is a wide spectrum of research and effort before and after that event. Considerable focus is placed on prevention and detection of an injury event in the form of a material or doctrinal solutions. Additionally, there is a tremendous effort in expanding treatment techniques after TBI has been detected. This study will focus on a potential method of detecting TBI directly following an acute injury. The primary domain of this study is military usage, although there are potential benefits to the athletic community. Participants for this study represented an age demographic (M=33, SD=5) slightly higher than the DOD mean. Figure 1.1 shows an age group breakdown of the active duty portion of the DOD during 2013. Participants of this study represent approximately 15% of the DOD [11].

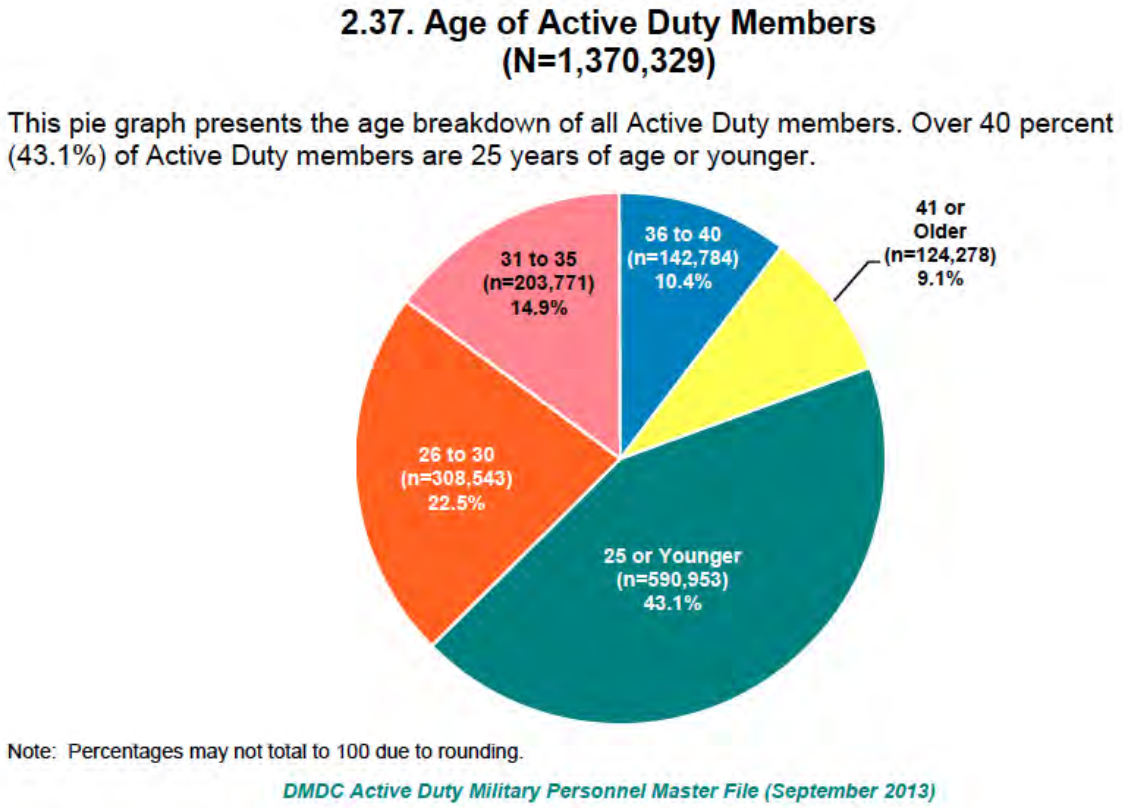

Figure 1.1: Age breakdown of all DOD active duty members for 2013. This year was the latest data available, from [11].

1.5 Thesis Organization

The rest of the thesis is organized as follows: Chapter 2 provides a literature review beginning with an overview of the prevalence of TBI and associated issues facing the DOD concerning TBI. The utilization of virtual environment (VE) as a diagnostic tool for neurological disorders and a summary of findings. Chapter 3 outlines the methodology utilized for this study. The overall design of the study, participant recruiting, implements used, and data collection are explained. Chapter 4 provides an analysis of collected data and discussion of results. Chapter 5 contains conclusions and recommendations resulting from the study and the author's evaluations.

CHAPTER 2:
Literature Review

Individual safety encompasses a wide range of subjects in the military domain. Training mishaps, enemy threats, and industrial accidents are a few of the hazards facing service members. Guidance for the acquisition of military equipment dictates that Human Systems Integration (HSI) specifically be utilized to consider occupational hazards and force protection issues [12]. In the context of head injuries, there is a significant body of research with the sole purpose of protecting and caring for a service member. If one thinks about an event that causes mTBI as being on a time line at zero, with actions leading up to that event occurring to the left and actions after the event to the right, there are distinct areas of research along that entire spectrum, see Figure 2.1. This chapter will provide a brief overview of those areas and describe the focus of this thesis.

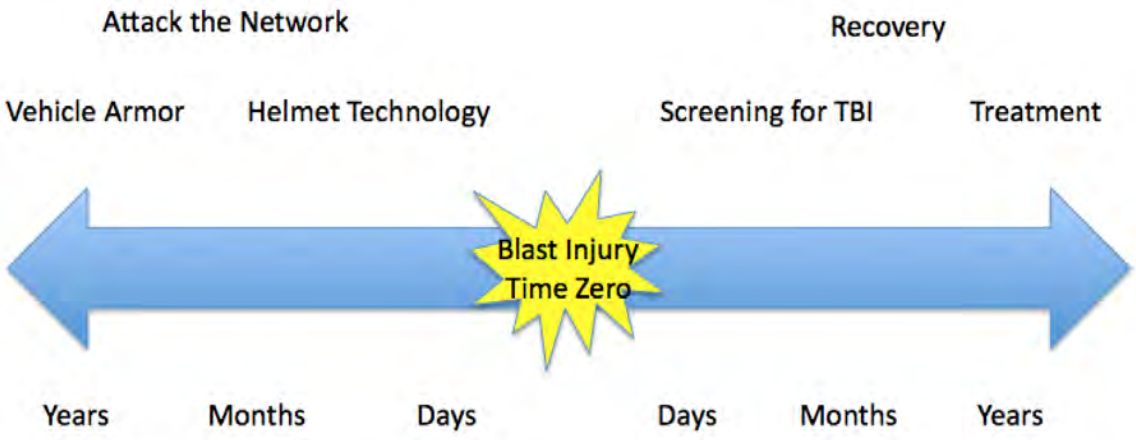

Figure 2.1: Time line of events surrounding a head injury event. Actions to the left of the blast are aimed at protection and prevention. Actions to the right of the blast are aimed at detection of a TBI and treatment in the long term.

2.1 Traumatic Brain Injury

One challenge facing mTBI research is simply determining an exact definition of the injury [13]. TBI is categorized in three different levels of severity; low, mild, and severe. The level

of severity does not directly correlate to potential for long-term ill effects. An individual can have a mild injury that has lasting negative effects on his or her quality of life [6]. It is further described by mechanism of injury: open or closed. Open-head trauma contains visible wounds and closed-head trauma shows no visible wounds.

Traumatic brain injury occurs when there is an associated head trauma or a sudden acceleration/deceleration force felt by the head. Unique to the military, are blast waves produced by explosions passing through the brain, resulting in trauma. During this trauma, the neurons that form connections in the brain literally shear apart and cease to function properly. The level to which shearing occurs and location of shearing depends largely on the severity of the injury itself. The result is improper neurological function as the brain attempts to reestablish broken connections between neurons [6].

For this thesis, mTBI describes a closed brain injury that results in altered cognitive, neurological, and/or physiological function.

2.2 Protection

Given that the mechanism of injury is typically trauma or a sudden jerk force, the immediate solution that comes to mind is to protect the individual's body from the force. Innovation in protecting the individual has accelerated over the last decade and continues to focus on HSI during acquisition [12]. These improvement are represented by Figure 2.1 in the years and months leading up to a potential injury event. Protection is broken into two categories here, one for personal body armor and one for vehicular armor.

2.2.1 Helmet Technology

When the first United States troops set foot in Afghanistan in early winter of 2001 and in Iraq in March of 2003, they were wearing Personnel Armor System for Ground Troops (PASGT) helmets designed and fielded in the early 1980s. While the helmet had not changed much in twenty years, it did offer National Institute of Justice (NIJ) Level IIIA protection. Level IIIA provides protection against handgun rounds up to a 240gr .44 Magnum bullet traveling at 1340 ft/s and fragmentation [14]. Figure 2.2 gives a sense of scale for body armor, there are two more levels above Level IIIA that encompass rifle rounds. The PASGT had no padding inside, a chin strap attached at two points, and a leather sweat band

attached with webbing inside the helmet. Though this setup provided protection against ballistic threats, it provided little in the way of impact/shock protection for the individual wearing it [15].

Armor Level	Protection
Type I (.22 LR; .380 ACP)	This armor would protect against 2.6 g (40 gr) .22 Long Rifle Lead Round Nose (LR LRN) bullets at a velocity of 329 m/s (1080 ft/s ± 30 ft/s) and 6.2 g (95 gr) .380 ACP Full Metal Jacketed Round Nose (FMJ RN) bullets at a velocity of 322 m/s (1055 ft/s ± 30 ft/s). It is no longer part of the standard.
Type IIA (9 mm; .40 S&W; .45 ACP)	New armor protects against 8 g (124 gr) 9×19mm Parabellum Full Metal Jacketed Round Nose (FMJ RN) bullets at a velocity of 373 m/s ± 9.1 m/s (1225 ft/s ± 30 ft/s); 11.7 g (180 gr) .40 S&W Full Metal Jacketed (FMJ) bullets at a velocity of 352 m/s ± 9.1 m/s (1155 ft/s ± 30 ft/s) and 14.9 g (230 gr) .45 ACP Full Metal Jacketed (FMJ) bullets at a velocity of 275 m/s ± 9.1 m/s (900 ft/s ± 30 ft/s). Conditioned armor protects against 8 g (124 gr) 9 mm FMJ RN bullets at a velocity of 355 m/s ± 9.1 m/s (1165 ft/s ± 30 ft/s); 11.7 g (180 gr) .40 S&W FMJ bullets at a velocity of 325 m/s ± 9.1 m/s (1065 ft/s ± 30 ft/s) and 14.9 g (230 gr) .45 ACP Full Metal Jacketed (FMJ) bullets at a velocity of 259 m/s ± 9.1 m/s (850 ft/s ± 30 ft/s). It also provides protection against the threats mentioned in [Type I].
Type II (9 mm; .357 Magnum)	New armor protects against 8 g (124 gr) 9 mm FMJ RN bullets at a velocity of 398 m/s ± 9.1 m/s (1305 ft/s ± 30 ft/s) and 10.2 g (158 gr) .357 Magnum Jacketed Soft Point bullets at a velocity of 436 m/s ± 9.1 m/s (1430 ft/s ± 30 ft/s). Conditioned armor protects against 8 g (124 gr) 9 mm FMJ RN bullets at a velocity of 379 m/s ±9.1 m/s (1245 ft/s ± 30 ft/s) and 10.2 g (158 gr) .357 Magnum Jacketed Soft Point bullets at a velocity of 408 m/s ±9.1 m/s (1340 ft/s ± 30 ft/s). It also provides protection against the threats mentioned in [Types I and IIA].
Type IIIA (.357 SIG; .44 Magnum)	New armor protects against 8.1 g (125 gr) .357 SIG FMJ Flat Nose (FN) bullets at a velocity of 448 m/s ± 9.1 m/s (1470 ft/s ± 30 ft/s) and 15.6 g (240 gr) .44 Magnum Semi Jacketed Hollow Point (SJHP) bullets at a velocity of 436 m/s (1430 ft/s ± 30 ft/s). Conditioned armor protects against 8.1 g (125 gr) .357 SIG FMJ Flat Nose (FN) bullets at a velocity of 430 m/s ± 9.1 m/s (1410 ft/s ± 30 ft/s) and 15.6 g (240 gr) .44 Magnum Semi Jacketed Hollow Point (SJHP) bullets at a velocity of 408 m/s ± 9.1 m/s (1340 ft/s ± 30 ft/s). It also provides protection against most handgun threats, as well as the threats mentioned in [Types I, IIA, and II].
Type III (Rifles)	Conditioned armor protects against 9.6 g (148 gr) 7.62×51mm NATO M80 ball bullets at a velocity of 847 m/s ± 9.1 m/s (2780 ft/s ± 30 ft/s). It also provides protection against the threats mentioned in [Types I, IIA, II, and IIIA].
Type IV (Armor Piercing Rifle)	Conditioned armor protects against 10.8 g (166 gr) .30-06 Springfield M2 armor-piercing (AP) bullets at a velocity of 878 m/s ± 9.1 m/s (2880 ft/s ± 30 ft/s). It also provides at least single hit protection against the threats mentioned in [Types I, IIA, II, IIIA, and III].

Figure 2.2: National Institute of Justice ballistic standards for body armor, after [14].

In the early 2000s, United States (U.S.) Special Operations Command (SOCOM) adopted the Modular Integrated Communications Helmet (MICH) as their standard helmet. The MICH offered slightly less coverage to accommodate communications headsets, lighter weight, and increased impact protection for the individual. The suspension/retention system in the MICH used a four-point strap system for increased stability on the individual's head. The leather sweat band and strap harness inside the PASGT was replaced by a foam padding system designed to absorb and dissipate impact [15].

The success of the MICH prompted the United States Army (USA) and United States Marine Corps (USMC) to use it as the basis for a replacement to the PASGT. In 2003, the Army adopted the Advanced Combat Helmet (ACH), which used shock-resistant padding and more robust retention systems to reduce impact related injuries. The Marine Corps chose the Lightweight Helmet (LWH) as a replacement and began fielding it in 2003. Al-

though an improvement over the PASGT, the early versions of the LWH did not have shock absorbing padding inside. The padding system of the LWH was not changed until several years later [16].

Improvements in ballistic protection and impact absorption have mitigated two main threats from blast injuries. Objects in motion impacting an individual's head and the body being thrown against something are indirect results of an explosion. Atmospheric over pressure is the primary result of explosions and produces a blast wave that travels through the body [15]. This blast wave predominately has adverse effects on the ears, lungs, and bowels, where liquids and gasses mix, but it can also produce a shearing effect among the brain's neurons. Despite these advancements in protective helmets, there remains no way to prevent explosive over pressure from traveling through the body [2].

2.2.2 Vehicle Armor

During the initial invasion of Iraq and Afghanistan between 2001 and 2003, support vehicles lacked the robust armor. The Army's and Marine's primary wheeled vehicles for troop and cargo transport, the Highly Mobile Multipurpose Wheeled Vehicle (HMMWV), Medium Tactical Vehicle (MTV), and Logistics Vehicle System (LVS) had little need for armor until this most recent conflict [1]. Logistics support and large troop transportation took place in the rear area which was considered safe until the early stages of OEF and OIF. These vehicles valued speed and cargo/troop carrying capacity over protection. Most provided little more than thin metal or canvas between the occupants and outside.

The most protected troops on the battlefield were those in armored units who utilized tanks and fighting vehicles on the front lines. With the advent of improvised explosive device (IED) to attack comparatively more vulnerable support troops, the incidence of blast-related injuries climbed. This increase resulted in blast injuries accounting for the majority of hazards on the modern battlefield [1]. As a result, armor kits were designed to retrofit existing vehicles and new vehicles were purchase with armor and survivability as a primary goal, such as the Mine Resistant Ambush Protected (MRAP) family of vehicles. While increased vehicle armor has saved many service member's lives, the risk of having a brain injury when involved in an IED blast inside one of the vehicles still remains [2].

2.3 Prevention

While protection is aimed at placing a barrier in between the individual and a hazard, prevention is aimed at avoiding the hazard all together. In the case of avoiding IEDs, being able to identify then reduce the threat and removing an enemy's capability to use IEDs as a weapon are the two main avenues of approaching the problem.

2.3.1 Removing the Hazard

As a result of the increased usage of and casualties from IEDs, the Army established an IED Task Force in 2003 with the main focus of reducing this threat [17]. From this task force, Joint Improvised Explosive Device Defeat Organization (JIEDDO) was born in 2006. DOD Directive 2000.19E formally established JIEDDO as a jointly manned activity and specified its mission, function, and authority [18]. During OEF and OIF, JIEDDO formed several subordinate task forces that were geographically specific to analyze threats unique to Afghanistan or Iraq.

JIEDDO employs a three pronged approach to removing or reducing explosive hazards on the battlefield. A robust intelligence capability allows them to track and identify bomb makers, financiers, suppliers, and emplacers. The goal here is to "attack the network" by removing one or multiple components necessary for the enemy to use IEDs against US forces [17]. Leveraging technology and a rapid acquisition ability, JIEDDO aims to "defeat the device" used against deployed troops [17]. Developing techniques and technology to detect, neutralize, and mitigate explosive hazards support this portion of their mission. The last approach used is a robust training effort to educate service members on the most up to date threats, how to plan for, avoid, and react to explosive hazards on the battlefield. Training programs range from detailed explanation of construction and employment of IEDs to increased observational skill sets such as the Marine Corps' Combat Hunter program [19]. This thrust is also the lead for developing doctrine and tactics, techniques, and procedures (TTP) for combating this threat [17].

2.4 The Injury

The aforementioned methods greatly increased the safety of service members in deployed environments, but IEDs remained a significant threat. Once a blast injury affects service members, the focus shifts to detection of an injury and treatment. In obvious cases of

individuals with a severe open TBI, they are removed from the battlefield at the soonest tactical convenience through casualty evacuation procedures. Those with no visible signs of injury will likely remain on the battlefield, even if they are experiencing the effects of mTBI.

In order to provide effective treatment as early as possible, it is necessary to determine if an individual has symptoms of a TBI. If an individual has a closed injury and does not experience a significant loss of consciousness (LOC), as in a momentary LOC, or no LOC at all, they will likely not know to self report a possible TBI. This becomes especially challenging in the chaos of a high stress combat scenario where an individual may not realize or remember there was a LOC or degraded cognitive performance. Since early detection and treatment are key to full recovery from a mTBI, simple and effective screening aides are important to target treatment to those who need it and return to duty those who so no signs of an injury [5], [13], [20]. An individual is particularly at risk of long lasting adverse effects if they receive a second TBI in the following days/weeks from their first [3], [5]. This may be a result of sustained combat operations where it is not tactically feasible to screen individuals for potential TBI immediately. When it is feasible to screen for TBI with tools that have limited impact on combat operations (ie. where service members do not need to be transported to a specialized facility with highly skilled medical personnel), the opportunity should be taken [20].

2.5 Assessing TBI

There are numerous methods used to determine if someone is suffering from mTBI. Detection methods range from objective measures such as blood sample analysis and magnetic resonance imaging (MRI) brain scans to subjective measures which are often in the form of verbally administered tests. This injury presents a challenge for diagnosis due to its often subtle and highly variable effects.

2.5.1 Objective Measures

Objective means for determining if a mTBI is present aim to accurately quantify some nature of the injury by a test. This often involves some specialized equipment to measure results and for the test itself. An objective test also has the potential of being more reliable as the effect of inter-rater reliability and bias is reduced [21], [22].

Objective detection methods that require specialized highly sensitive equipment, skilled technicians to operate, laboratories to test results, or that require lengthy lead times are not feasible in deployed austere environments specific to the military domain. Though a service member might be able to receive an MRI in a military hospital in Germany within 24 hours of the time they were injured in a mature theater such as Iraq, there is no guarantee that such services will be widely available to deployed personnel. The military requirements for an accurate detection method are something that will withstand the rigors of frequent transport and in less than surgery room levels of cleanliness, is easy to use, and presents real time results [7].

2.5.2 Neuroimaging

A common tool used to assist clinicians in determining a possible TBI is neuroimaging. The two most commonly used methods are computed tomography (CT) and MRI scans, with CT scans providing lower fidelity to the later [22]. Neither is used as a stand alone tool for assessing potential TBI, but used to assist the clinician with a determination. The decision to use one of these scans is not automatic when assessing a patient. If there are warnings and indicators of a TBI (such as a self reported LOC less than 30 minutes or visible trauma), a neuroimaging scan will likely be ordered. Patients with more subtle symptoms may not receive a scan [23].

The CT scan is most commonly used due to the speed of evaluation and lower cost. Despite these advantages, a CT scan can only detect anomalies in the physical structure of the brain and has a potential health risk associated with ionizing radiation used for the scan. The main advantage of CT scans are the detection of intracranial lesions, which serve as a prime indicator of the presence of a TBI although a TBI may exist with no intracranial lesions [22], [23].

A MRI is a more expensive and time consuming alternative to the CT scan and does not pose a risk from ionizing radiation. The advantage of an MRI is its ability to assess physical structure and function of the brain. This ability provides more insight into the nature of an injury on an individual and can greatly assist a clinician in making a determination. However, there is a possibility that an MRI will show normal function even if the individual has a TBI [22], [23].

Despite their advantages, these detection methods remain on the higher end cost, and require dedicated infrastructure and personnel to operate. These qualities preclude their use on a mass scale in an austere environment.

2.5.3 Other Objective Methods

There are other objective measures for potentially detecting the presence of a mTBI that are less mature but worthy of note none-the-less. Placing sensors in an individual's helmet to detect impact force and using blood tests near the point of injury.

Sensor systems placed in helmets gained interest with the DOD shortly after the National Football League (NFL) began using them in player's helmets [7]. The basic premise for the multiple sensor systems on the market is the same, place a data recorder in a helmet with an accelerometer to determine if an individual has been exposed to sufficient impact, acceleration, or deceleration to warrant further investigation. While this technique has shown positive results in the relatively controlled environment of the football field, it has mixed reviews in the military domain [7]. The primary detractors from using sensor systems are the number of false positives, sensor orientation, reading data from a large number of helmets, and cost. Military helmets take a large amount of abuse, while being worn and when not being worn. Some of this abuse is sufficient enough to trigger a positive reading, such as a helmet falling off the hood of a vehicle when not being worn. Most sensors on the market also require a specific orientation to function correctly, which is not feasible in the military domain. Once data is collected it must be transferred to, and read by, someone who can interpret it. These factors make current sensor technology cost prohibitive for large forces [7].

Using blood chemistry as an indicator of a mTBI, when no visible signs of behavioral change exist, is a promising realm of objective measures [7]. Testing methodology involves taking a blood sample from potentially affected individuals in the field and analyzing the sample on location. Potential candidates for biomarkers include: S100B, glial fibrillary acidic protein, and neuron-specific enolase [7]. The two main challenges associated with this method are the development of an effective field portable test and Food and Drug Administration (FDA) approval of these markers as an indicator of mTBI.

2.5.4 Balance

Sustaining a mTBI has an acute effect on an individual's ability to balance in the subsequent days following an injury. As the body attempts to repair the broken connections of neurons in the brain resulting from an injury, it increases its glucose metabolism for a period of approximately six hours following injury [8]. After this period, glucose metabolism slows to an abnormal rate for up to five days. The result of this imbalance is an adverse effect on the individual's ability to maintain balance [8], [24].

Objective measures of balance can be conducted using computerized dynamic posturography, where a computer assesses balance through the use of a force plate and visual inputs [25]. Medical grade devices, such as the NeuroCom EquiTest, use a sensory organization test (SOT) to measure balance. The SOT assesses the three components of balance through six conditions of varying visual and somatic input. The SOT uses sway, the anterior posterior (AP) and medial lateral (ML) movement of an individual, to score balance on a 100 point scale with the high end being perfect balance and a score of zero showing no ability to balance. This test has shown degraded balance ability in individual's affected by a TBI [25], [26].

Similar to the SOT, the Clinical Test for Sensory Integration of Balance (CTSIB) assesses postural stability through four conditions of varying degrees of visual and somatic input [27]. It uses a sway index as the standard deviation from the individual's average center of mass. Similarly, computerized dynamic posturography devices use this technique to assess balance. Specifically, the Biodex Balance System and BioSway utilize this technique [27].

The use of an individual's center of pressure (COP) is a common method used to measure balance [28]. One can think of COP as an individual's center of mass projected down to the ground, representing the point over which the center of mass is located. Measuring the movement of COP falls into two main categories: how far it moves, sway, and how fast it moves, velocity. The use of COP sway and velocity as an indicator of postural control has been proven as a reliable method with velocity providing the best indicator [28], [29], [30].

These devices, while cheaper than a MRI or CT scan, cost in the tens of thousands of dollars range. While popular with the professional sports and physical therapy industry, they do not offer the portability or ease of use needed in the austere environment of deployed

troops. There are conflicting opinions concerning the usefulness of quantitative balance measures. In particular, some researchers suggest that subjective screening tests are just as effective in diagnosing TBI [31] while others consider the use of devices capable of accurately measuring balance as a more effective method for assessing TBI [31], [32].

2.5.5 Subjective Measures

Subjective measures for evaluating individual's with potential TBI are typically administered by a clinician familiar with the screening method. They are observational in nature with written results being tallied for a final score that serves as an indicator. They have the advantage of being able to be administered in most settings and are simple to use. However, reliability between administrators is questionable [7], [31].

Glasgow Coma Scale

The Glasgow Coma Scale (GCS) was developed by Graham Teasdale and Bryan J. Jennett at the University of Glasgow's Institute of Neurological Sciences in 1974 [33]. It was originally designed to assess a patient's level of consciousness in an Intensive Care Unit (ICU) setting though it is now widely used by clinicians and first responders to assess head injuries. The assessment tests eye, verbal, and motor responses and assigns a score according to the level of response. Scores range from 0 to 15 (the original scale used a high score of 14 and has since been modified to 15) with 0 being completely unresponsive and 15 indicating potential for a mTBI. These scores are used to indicate the severity of a head injury and provide an indicator if one exists. Figure 2.3 shows the rating system. Much of the literature reviewed uses the GCS as a comparison standard for other methods of determining a TBI [31], [33].

The literature reviewed suggests that there is no single standard for representing a score for a TBI on the GCS. Some literature indicates a mTBI being present with a GCS of >13, while others use a GCS of >12. Severe TBI has a score of <8 in some literature and <9 in others. Moderate TBI exists on the range between theses scores. Figure 2.4 shows one version of level of severity of TBI on the GCS [5], [31].

Even though the GCS has been demonstrated to be a useful, easy-to-use tool capable of evaluating the severity of a TBI [7], it does rely on a clinician's observations and is subject to inter-rater reliability concerns. For example, in 2004, Gill, Reiley, and Green in-

Response	Score
Eye opening	
Opens eyes spontaneously	4
Opens eyes in response to speech	3
Open eyes in response to painful stimulation (eg, endotracheal suctioning)	2
Does not open eyes in response to any stimulation	1
Motor response	
Follows commands	6
Makes localized movement in response to painful stimulation	5
Makes nonpurposeful movement in response to noxious stimulation	4
Flexes upper extremities/extends lower extremities in response to pain	3
Extends all extremities in response to pain	2
Makes no response to noxious stimuli	1
Verbal response	
Is oriented to person, place, and time	5
Converses, may be confused	4
Replies with inappropriate words	3
Makes incomprehensible sounds	2
Makes no response	1

Figure 2.3: Evaluation criteria for the modified Glasgow Coma Scale, after [33].

TBI Classification	Length of Loss of Consciousness	Length of Amnesia	Glasgow Coma Scale Score
Mild TBI (mTBI)	< 20 minutes	< 24 hours	GCS > 13+
Moderate TBI	> 20 minutes, but < 6 hours		GCS 9 - 12
Severe TBI	> 6 hours		GCS < 8

Figure 2.4: Traumatic Brain Injury classification criteria using the modified Glasgow Coma Scale, after [33] .

vestigated the reliability of the GCS in an emergency room setting. The researchers examined 116, independently assessed GCS scores made by emergency physicians. Their results demonstrated that only moderate agreement (32%) exists between raters total GCS scores [21].

Military Acute Concussion Evaluation

Military practitioners developed and adopted an assessment similar to the GCS into the Military Acute Concussion Evaluation (MACE). The MACE is a verbally administered assessment conducted by a trained clinician that includes an examination, details of the nature of the injury, and symptoms experienced by the patient. The two main portions of the MACE include the individual's history of possible mechanisms for head trauma and observations of examination results by the clinician. The second portion utilizes the Standardized Assessment of Concussion (SAC) to measure cognitive performance. The SAC has a scoring range of 0 to 30 with a rating of 24 as the generally accepted threshold

indicator for a possible TBI (higher scores indicate reduced likelihood of a TBI) [34]. It serves as a screening tool to assist medical providers in determining if a TBI is present.

Though the MACE is a valuable tool to assist medical providers in screening individual's with a potential TBI, there are challenges and limitations associated with its use. Despite being an easy to follow guide (see Appendix A), standard training and evaluation for the use of the MACE is lacking with military medical providers [35]. Since no individual baseline score is maintained for an individual evaluated using the MACE, the individual may score at or below the accepted threshold without having a TBI [34], [35]. Additionally, a study conducted by R. L. Coldren et. al [35] suggests the MACE lacks the sensitivity necessary to detect a mTBI past 12 hours from the time of injury.

2.6 Virtual Environments Diagnosis and Treatment

The use of VE for the treatment of varying medical conditions is a domain that has shown promising results, particularly with psychological or neurological disorders [36], [37]. Though the treatment realm has shown the successful use of VE, use in the diagnosis realm has not shown the same advancement [38]. Virtual environments offer unique advantages for use in aiding the diagnosis of psychological and neurological disorders. Their use provides a controlled, tailorable, and safe environment where measurements can be precisely recorded. In cases where the VE is used to replace a test setting, say a planning task to shop for groceries as a test of executive dysfunction, use of a VE was just as good, and better in some regards to the real world test setting [38], [39]. In some cases, testing conditions are not feasible using real world environments, such as a spinning room or using an object to solicit a fear response. The relative ease of being able to create or adjust a testing environment and having the capability to measure dependent variables associated with a particular test make the utilization of a VE viable for obtaining an objective measure for potentially indicating a TBI.

2.7 Summary

The shift in mechanism of injury during recent conflicts and advancements in protective equipment have resulted in an increase in proportion of blast inflicted head trauma casualties. There have been significant efforts to prevent these injuries from happening and in treatment once they occur. A necessary prerequisite for treating brain injuries is utilizing

an effective screening technique to target treatment for those individuals who need it most. Requirements for an accurate detection method in the military domain are a system that will withstand the rigors of frequent transport, performs in austere environments, is easy to use, and presents real time results [12]. Detection methods that require specialized highly sensitive equipment, skilled technicians to operate, laboratories to test results, or that require lengthy lead times are not feasible in deployed austere environments specific to the military domain. Though a service member might be able to receive an MRI in a military hospital in Germany within 24 hours from the time they were injured in a mature theater such as Iraq, there is no guarantee that such services will be widely available to deployed personnel in the future. While simple to use, subjective measures are largely guidelines which are open to the interpretation and observation of the individual administering the test. Having an objective measure, suited for use in an expeditionary environment, to assist medical providers in the diagnosis of a TBI would be beneficial. Of particular interest to the research conducted for this thesis is the use of balance as an indicator of potential head trauma.

The portion of the time line of events surrounding a blast injury, see Figure 2.1, that this thesis focuses on is the period of hours and days directly following an injury producing event. Measuring balance with the aide of a VE using commercial off-the-shelf (COTS) technology is the method chosen in this thesis for ultimately attempting to determine the presence of a mTBI. The use of VETS has potential to be a feasible test in a austere deployed environment.

This thesis aims to determine the reliability of the VETS device as an objective evaluation tool for balance using human subject research. Also, the feasibility of this device for use in the military domain will be investigated. The device measures COP sway and velocity, and root mean square (RMS) AP and ML. The primary focus of analysis with center on COP sway and velocity due to its proven reliability for measuring postural control.

THIS PAGE INTENTIONALLY LEFT BLANK

CHAPTER 3:
Methodology

3.1 Overview

This chapter focuses on the overall setup and execution of human subject testing with the VETS device. Details about the VETS device and procedures participants were asked to perform are explained. The purpose of this chapter is to provide a guide that may be used for repeatability of the experiment.

3.2 Participants

The population of interest is active duty US military personnel. Per Naval Postgraduate School's approved institutional review board (IRB), subjects were recruited from the student body. Appendix B includes a copy of the institutional review board approval for this study. Recruitment occurred through flyers and word of mouth. No special skill sets or experience was necessary for potential subjects. Subjects were excluded from the study if they had sustained a documented head injury within the last month. This condition did not apply to any volunteer and all were able to participate in the study. Appendix C is an example of the recruitment flyer.

3.3 Apparatus

The VETS device includes all electronics, peripherals, foam pad, and accompanying stands needed to conduct testing. An updated software suite to control all components, provide a VE, and collect data is used as well.

3.3.1 VETS

The hardware includes several basic pieces; a large television screen, a computer, a Wii Balance Board, and an Airex foam pad. All components fit onto a metal TV stand with an adjustable height, wheels, and a platform at waist level.

Software

The VETS software suite collects data, using a Wii Balance Board as an input device, at 100 Hz. This collection rate is comparable to medical grade balance research devices such as Natus Medical Incorporated and AMTI Biomechanics force plates [9].

The VETS software suite requires the user to create a Vets/Results directory within the Asus minicomputer's Documents folder prior to install. The purpose of the directory is to provide the software suite a dedicated location to store collected data. Within Results, VETS software creates folders for each run of an experiment.

Once the Results directory has been created and the balance board paired, VETS software will function properly. Double clicking on the desktop VETS shortcut will start the software suite, which automatically detects the presence of the balance board. The graphic user interface (GUI) is a window with four main options at the top. The "Live" option provides a Cartesian Coordinate grid with a blue dot indicating the center of balance detected by the balance board. This section is dynamic and gives a visual indicator of movement by the user as indicated by the blue dot, which shifts according to the user's balance. The "Results" option provides bar graphs indicating differing results according to four measures of effectiveness (MOE). The "Settings" option allows for various runs of the experiment to be selected individually, at random, or in a standard format. Runs of the experiment include; still scene no foam, still scene with foam, eyes closed no foam, eyes closed with foam, dynamic scene no foam, dynamic scene with foam. The "Play" option allows a session name to be input by the user and for the duration of the experiment to be input in seconds.

Once all desired settings are input an experiment can be run. The software suite collects data automatically during each run and saves the data set as an Excel document in the Results directory. Overall, the software is relatively straightforward to operate. There are several acronyms used for the MOE that need to be explained as to what they are measuring and in what units. Data in the Excel file appears to be x and y coordinates for the center of balance from the balance board over time, but again no explanation of what is being measured appears in the Excel file.

Computer

The computer, which will control the visual output to the user and collect balance data from the WBB, is an Asus VM60. This is part of Asus's VivoPC line of non-traditional desktops as it is about the size of a Java textbook and is advertised as being a "mini" computer with the power of a full sized desktop. The computer runs Windows 8 with a 1.8 GHz processor and 4 GB of RAM.

Display

The television, used to provide the visual conditions, is a LG 60-inch 1080P resolution Light Emitting Diode (LED) screen.

Input Devices

The balance board is the standard Wii model produced by Nintendo. The dimension the user has to stand on is approximately 20 inches by 12.4 inches and is 2.1 inches tall. The WBB can accommodate users weighting up to 330 pounds. Peripherals include wireless keyboard and mouse to control the computer along with necessary cables to connect the components.

3.3.2 Questionnaires

Surveys were used to assist in determining possible confounding factors among subjects and to determine if the VETS device might have any adverse affect on subjects. Two surveys were used to accomplish this, a demographic survey and a simulator sickness questionnaire.

Demographics Survey

A demographic survey is administered prior to the VETS battery. The demographic survey includes questions about the subject's age, height, weight, handedness, military service, and if they have been diagnosed with a concussion in their life. Appendix E is an example of the demographic survey.

Simulator Sickness Questionnaire

A standard simulator sickness questionnaire was used to determine if the VETS Virtual Environment had an adverse affect on subject [40]. The questionnaire was administered

prior to the VETS battery. Subjects were asked if any of the conditions listed on the questionnaire had increased or decreased during the experiment. Appendix D is an example of the simulator sickness questionnaire.

3.4 Implementation and Data Collection

3.4.1 VETS

The vets software suite has the capability to measure balance under six different conditions. There are two platform conditions and three visual conditions. The user can either stand on a bare WBB or stand on the WBB with an Airex foam pad on top. Visual conditions include a static scene consisting of a VE scene, a rotating VE scene, and a blank scene in which the user closed their eyes. The leading edge of the WBB was placed 16 inches from the TV to provide for more immersion. Figure 3.1 shows a demonstration of the VETS device. The individual in the picture is not a participant in the study and is only posing for a demonstration photo. Also of note, participants in the study were not wearing their shoes during testing and the WBB was closer to the display platform.

Visual conditions began once the investigator started recording data and ended after 30 seconds. Examples of the visual scenes show the exact scenes a participant would see. Figure 3.2 shows an example of the static scene. Figure 3.3 shows the blank scene in which participants were instructed to close their eyes and maintain balance. At the end of 30 seconds, the participant was told to open their eyes and prepared for the next testing condition. Figure 3.4 shows an instantaneous screen shot of the dynamic scene. This scene was the same picture from the static scene rotated about several axes. The rotational direction, clockwise or counterclockwise, changed between trials.

Subjects attended two testing sessions with the second session occurring a week after the first. A longitudinal study was chosen to determine reliability of the VETS device and to investigate if a change index exists when using the device. Each session consisted of six different testing conditions conducted three times each for a total of 18 trials per session. Each trial lasted for 30 seconds of data collection, between trials subjects were given a rest period. The first three trials in a session were standard (eyes open firm board, eyes closed firm board, and dynamic foam board) with the remaining 15 conditions being randomly presented.

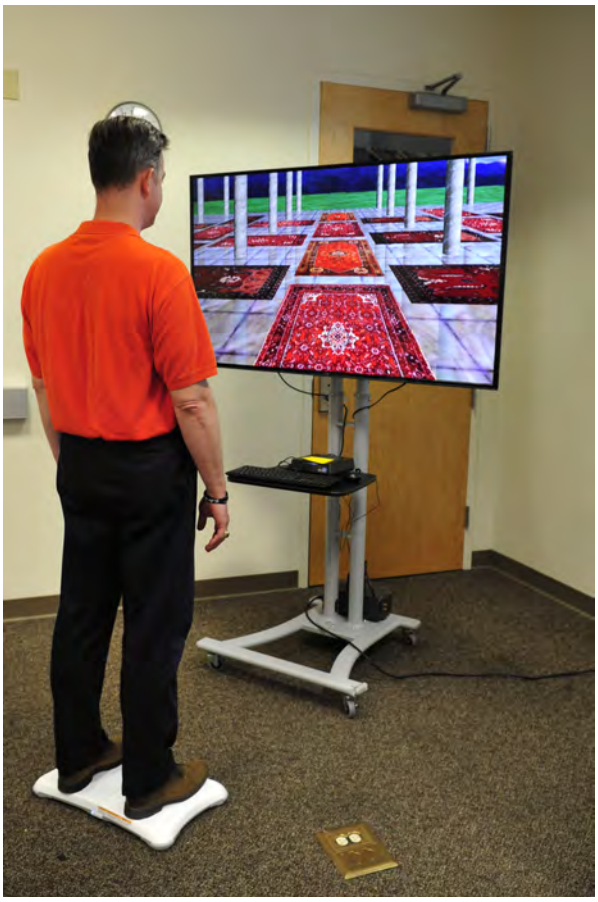

Figure 3.1: Demonstration photo of an individual, not a study participant, using the VETS device. Of note, participants did not wear shoes during testing and the WBB was much closer to the display platform.

The VETS software suite takes input from the WBB and calculates four different measurements to give an indication of balance. For each condition, COP sway area in cm^2, COP velocity in cm/sec, RMS AP in cm, and RMS ML in cm are measured and recorded. The COP can be thought of as a participant's center of gravity projected onto the WBB in two dimensions. Sway area is a measure of the area covered by the COP. RMS AP and ML measure the root mean squared of the forward and back movement and left and right movement respectively. These measurements give an indication of balance ability for the participant [8], [31].

For each participant, the investigator manually inputs testing information into the VETS software suite. Subject identification number, trial length, and condition order are all se-

Figure 3.2: Static visual scene presented to the participant during testing. Participants maintained balance as best as possible for 30 seconds while viewing this scene.

lected from graphic user interface (GUI) such as in Figure 3.5. Once all parameters are set, testing can begin.

3.5 Data Entry and Formatting

It was necessary to consolidate data from the VETS software suite and questionnaires into one master document for ease of analysis. Excel was chosen for the master document for its compatibility with Statistical Package for the Social Sciences (SPSS) and ability to process simple statistics on demographic information.

3.5.1 VETS

The VETS software suite produced 540 Excel files for the 15 participants who took part in this study. Each Excel file contained coordinate data for COP over time and four measurements for each condition. These measurements were copied and input into the master Excel file by subject, session, trial, and condition.

Figure 3.3: Blank visual scene presented to the participant during testing. Participants maintained balance as best as possible for 30 seconds during this scene. Once the screen went to black, the participants were instructed to close their eyes during the test. When the 30-second trial was finished, the investigator informed the participants that they could not open their eyes.

3.5.2 Questionnaires

Demographic Survey

Demographic data collected from surveys were manually input into the master Excel data document. Participants were identified by subject identification number, not by personally identifiable information.

Simulator Sickness Questionnaire

Nothing of significant interest was found after reviewing Simulator Sickness Questionnaire (SSQ) data collected from participants. As such, this information was not captured in the master Excel data document.

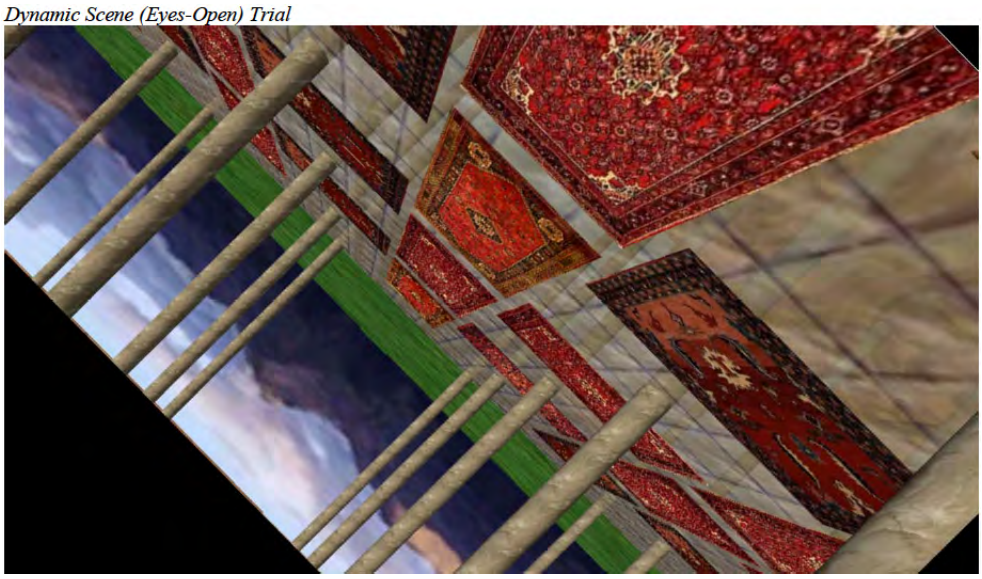

Figure 3.4: Dynamic visual scene presented to the participant during testing. Participants maintained balance as best as possible for 30 seconds while viewing this scene. The dynamic scene rotated about several axes. The direction of rotation, counterclockwise or clockwise, changed between trials.

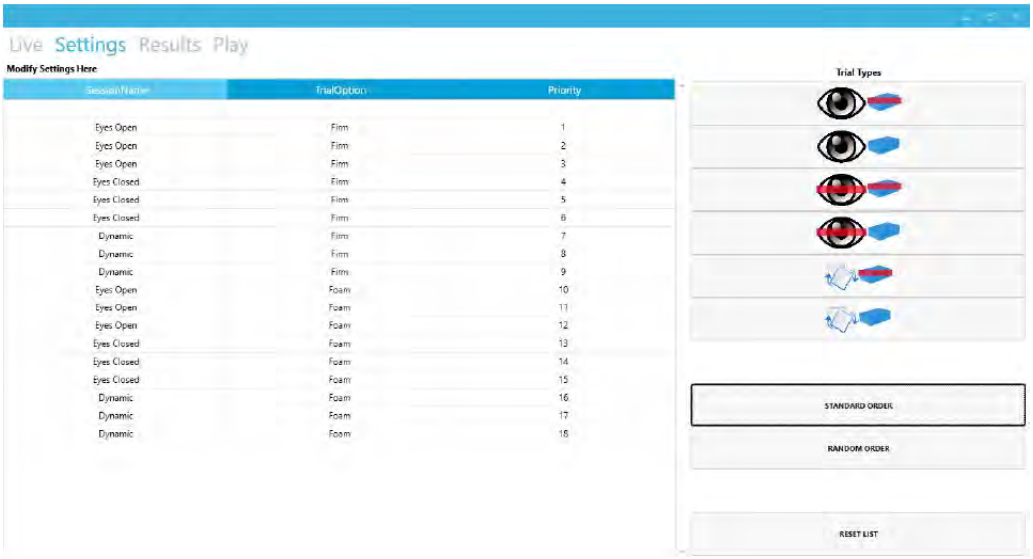

Figure 3.5: Screen shot of the VETS graphic user interface. Testing conditions and order can be selected from this screen. Subject identification, trial length and testing rate in hertz can be designated from a similar screen.

CHAPTER 4:
Results and Discussion

4.1 Overview

Raw data from the VETS device were output into an Excel file for each condition and measurement. These data were compiled into one master Excel file with demographic data added. This provided an easy format to input into statistical software for analysis. Simple statistics on demographic data are provided in the first part of this chapter. Significant results from the analysis of VETS performance measures are presented in the latter half of this chapter. All analyses were conducted using SPSS 19 for Windows. Unless otherwise noted, an alpha level of 0.05 was used to indicate significant effects. SPSS's Descriptive function was used to examine all data for skewness and kurtosis. Variables which were not normally distributed were transformed using the Transform function in SPSS. Mean substitutions were used to replace two instances of missing data.

4.2 Analysis of Demographic

Participants were asked to fill out a demographic survey prior to experimentation. Information given was voluntary with the goal of determining potential confounds. The majority of the participants in this study, 14, were commissioned officers and 1 participant was a Staff Non Commissioned Officer.

4.2.1 Age

The mean age among subjects was 32.9 years (SD = 4.7). The oldest participant was 43 and the youngest was 27, see Figure 4.1.

4.2.2 Gender

Out of the 15 participants, 12 were male and 3 were female.

4.2.3 Service

Three services were represented in this study. Twelve participants were members of the USMC. Two participants were members of the United States Navy (USN). One participant

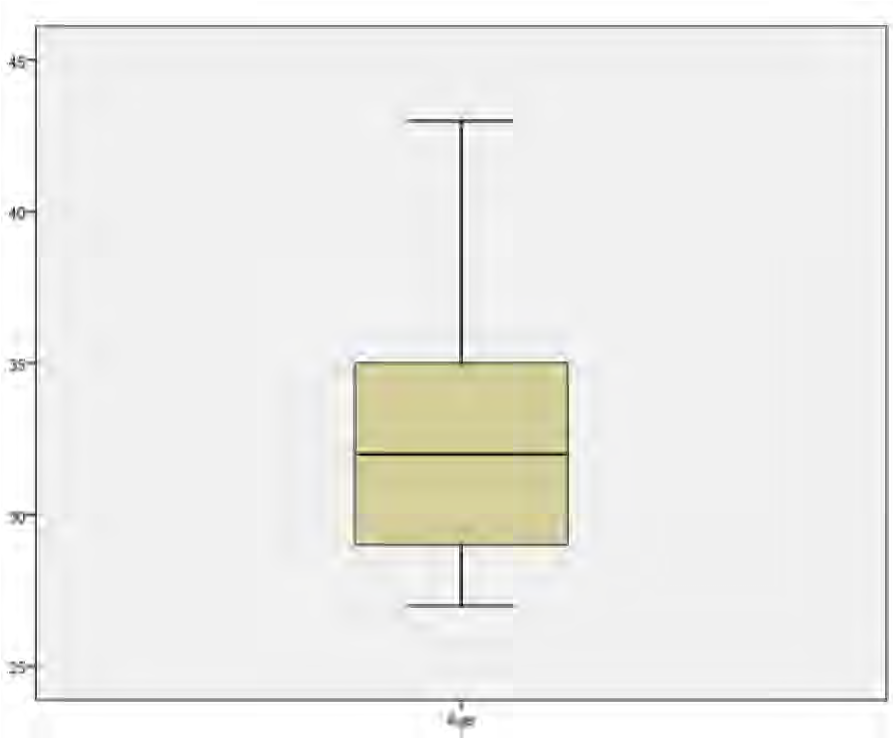

Figure 4.1: Box plot of mean and standard deviation for age of the 15 participants in the Baseline Establishment of Balance using the VETS device study.

was a member of the USA. Participants were at the mid point of their careers with a mean time in service of 11.5 years (*SD* = 4.6), see Figure 4.2.

4.2.4 Height, Weight, and Handedness

The mean height of participants was 69.3 inches (*SD* = 4.2), see Figure 4.3. The mean weight of participants was 182.7 pounds (*SD* = 36.9), 4.3. Two participants were left handed.

4.3 Simulator Sickness Questionnaire Data

There were no significant differences between participants' reported SSQ baseline scores and any of their post-trail scores.

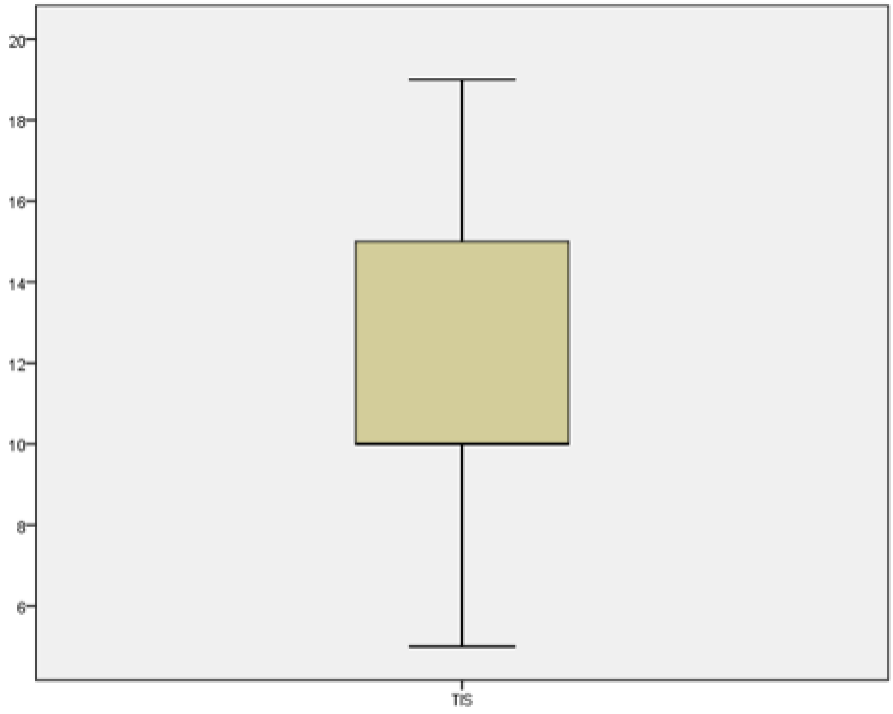

Figure 4.2: Box plot of mean and standard deviation for time in service of the 15 participants in the Baseline Establishment of Balance using the VETS device study.

4.4 Analysis of VETS System Collected Measures

First, a paired-samples t-test was conducted to examine reliability correlations and to compare the means of each VETS performance measure between the first, second and third trial of each session. Next, a one-way repeated measure analysis of variance (ANOVA) was used to examine any differences across testing days within VETS performance measures. Finally, a post-hoc repeated measures ANOVA was performed which examined VETS COP sway and velocity performance measures across both sessions in order to examine differences which existed over time. Means and standard deviations for sway is measured in cm^2, for velocity is measured in cm/sec, and RMS AP and ML are measured in cm. Lower numbers on measurements are considered better postural control while higher number indicate worse postural control.

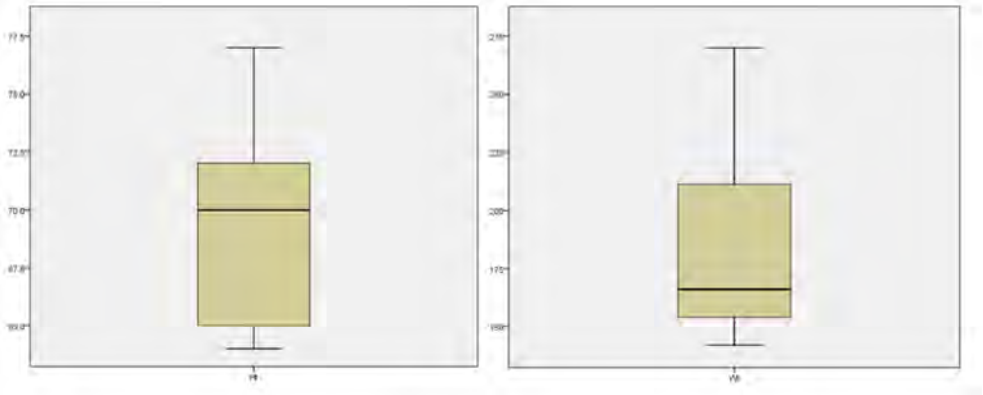

Figure 4.3: The box plot on the left is of mean and standard deviation for height of the 15 participants in the Baseline Establishment of Balance using the VETS device study. The box plot on the right is of mean and standard deviation for weight of the 15 participants in the Baseline Establishment of Balance using the VETS device study.

4.4.1 Paired Samples t-Test Results

A paired-samples t-test was used to compare each of the sway and velocity measures for all conditions by session (first session and second session). Results indicated that most of the variables were not significantly different. However, analysis of the test statistics revealed significant differences between trials for some measures. See Tables 4.1 - 4.12 for results on each sway and velocity measure group. Those with significant differences are indicated with an asterisk (*). Some negative t-values exist in the associated t-test tables, this indicates the direction of the difference in sample means.

4.4.2 Repeated Measures Results

A repeated measures analysis of variance was conducted to assess the differences between the session day (first session or second session) for each VETS performance measure. The repeated measure was each VETS performance measure on the first session and on the second session. Means and standard deviation for sway is measured in cm^2, for velocity is measured in cm/sec, and RMS AP and ML are measured in cm.

Firm Platform Dynamic Scene

Significant differences were found for the firm platform dynamic scene condition of the VETS performance measures between the first and second sessions, see Table 4.13.

Firm Dynamic Center of Pressure Sway

	M	*SD*	*t*	Sig. (2-tailed)
Session 1, Trial 1	4.21	3.20	-.222	.827
Session 1, Trial 2	4.39	3.71		
Session 1, Trial 1	4.21	3.20	.470	.520
Session 1, Trial 3	3.88	2.03		
Session 1, Trial 2	4.39	3.71	.660	.645
Session 1, Trial 3	3.88	2.03		
Session 2, Trial 1	3.25	3.05	-.016	.988
Session 2, Trial 2	3.26	2.09		
Session 2, Trial 1	3.25	3.05	.442	.665
Session 2, Trial 3	3.05	2.90		
Session 2, Trial 2	3.26	2.09	.279	.784
Session 2, Trial 3	3.05	2.90		

Table 4.1: Paired-samples t-test results for Firm Dynamic Center of Pressure Sway.

Firm Dynamic Center of Pressure Velocity

	M	*SD*	*t*	Sig. (2-tailed)
Session 1, Trial 1	2.18	0.49	-.107	.916
Session 1, Trial 2	2.19	0.55		
Session 1, Trial 1	2.18	0.49	.349	.732
Session 1, Trial 3	2.16	0.48		
Session 1, Trial 2	2.19	0.55	.594	.562
Session 1, Trial 3	2.16	0.48		
Session 2, Trial 1	2.07	0.43	-.088	.931
Session 2, Trial 2	2.07	0.34		
Session 2, Trial 1	2.07	0.43	1.37	.192
Session 2, Trial 3	1.97	0.32		
Session 2, Trial 2	2.07	0.34	1.47	.162
Session 2, Trial 3	1.97	0.32		

Table 4.2: Paired-samples t-test results for Firm Dynamic Center of Pressure Velocity.

Firm Eyes Open Center of Pressure Sway

	M	*SD*	*t*	Sig. (2-tailed)
Session 1, Trial 1	4.16	6.86	.997	.366
Session 1, Trial 2	2.56	3.25		
Session 1, Trial 1	4.16	6.86	.887	.390
Session 1, Trial 3	2.76	1.90		
Session 1, Trial 2	2.56	3.25	-.366	.720
Session 1, Trial 3	2.76	1.90		
Session 2, Trial 1	1.65	1.46	-.972	.347
Session 2, Trial 2	2.09	1.66		
Session 2, Trial 1	1.65	1.46	.207	.839
Session 2, Trial 3	1.56	1.07		
Session 2, Trial 2	2.09	1.66	1.28	.222
Session 2, Trial 3	1.56	1.07		

Table 4.3: Paired-samples t-test results for Firm Eyes Closed Center of Pressure Sway.

Firm Eyes Closed Center of Pressure Velocity

	M	*SD*	*t*	Sig. (2-tailed)
Session 1, Trial 1	1.93	0.31	-2.14	.050
Session 1, Trial 2	2.04	0.38		
Session 1, Trial 1	1.93	0.31	-2.88	.012*
Session 1, Trial 3	2.16	0.49		
Session 1, Trial 2	2.04	0.38	-1.21	.247
Session 1, Trial 3	2.16	0.49		
Session 2, Trial 1	1.89	0.33	-.82	.425
Session 2, Trial 2	1.94	0.25		
Session 2, Trial 1	1.89	0.33	-1.44	.173
Session 2, Trial 3	1.99	0.31		
Session 2, Trial 2	1.94	0.25	-1.01	.330
Session 2, Trial 3	1.99	0.31		

Table 4.4: Paired-samples t-test results for Firm Eyes Closed Center of Pressure Velocity.

Firm Eyes Open Center of Pressure Sway

	M	*SD*	*t*	Sig. (2-tailed)
Session 1, Trial 1	4.16	6.86	.997	.366
Session 1, Trial 2	2.56	3.25		
Session 1, Trial 1	4.16	6.86	.887	.390
Session 1, Trial 3	2.76	1.90		
Session 1, Trial 2	2.56	3.25	-.366	.720
Session 1, Trial 3	2.76	1.90		
Session 2, Trial 1	1.65	1.46	-.972	.347
Session 2, Trial 2	2.09	1.66		
Session 2, Trial 1	1.65	1.46	.207	.839
Session 2, Trial 3	1.56	1.07		
Session 2, Trial 2	2.09	1.66	1.28	.222
Session 2, Trial 3	1.56	1.07		

Table 4.5: Paired-samples t-test results for Firm Eyes Open Center of Pressure Sway.

Firm Eyes Open Center of Pressure Velocity

	M	*SD*	*t*	Sig. (2-tailed)
Session 1, Trial 1	1.79	0.35	-.072	.944
Session 1, Trial 2	1.80	0.32		
Session 1, Trial 1	1.79	0.35	-.023	.982
Session 1, Trial 3	1.79	0.24		
Session 1, Trial 2	1.80	0.32	.098	.924
Session 1, Trial 3	1.79	0.24		
Session 2, Trial 1	1.64	0.22	-1.66	.120
Session 2, Trial 2	1.70	0.25		
Session 2, Trial 1	1.64	0.22	-1.64	.123
Session 2, Trial 3	1.68	0.23		
Session 2, Trial 2	1.70	0.25	.723	.481
Session 2, Trial 3	1.68	0.23		

Table 4.6: Paired-samples t-test results for Firm Eyes Open Center of Pressure Velocity.

Foam Dynamic Center of Pressure Sway

	M	*SD*	*t*	Sig. (2-tailed)
Session 1, Trial 1	29.17	13.81	-0.049	.156
Session 1, Trial 2	24.25	13.33		
Session 1, Trial 1	29.17	13.81	-1.295	.002*
Session 1, Trial 3	19.78	37.90		
Session 1, Trial 2	24.25	13.33	-1.185	.164
Session 1, Trial 3	19.78	37.90		
Session 2, Trial 1	18.57	11.71	1.474	.092
Session 2, Trial 2	14.87	7.81		
Session 2, Trial 1	18.57	11.71	1.089	.076
Session 2, Trial 3	14.31	5.98		
Session 2, Trial 2	14.87	7.81	0.139	.622
Session 2, Trial 3	14.31	5.98		

Table 4.7: Paired-samples t-test results for Foam Dynamic Center of Pressure Sway.

Foam Dynamic Center of Pressure Velocity

	M	*SD*	*t*	Sig. (2-tailed)
Session 1, Trial 1	29.17	19.65	1.51	.156
Session 1, Trial 2	24.25	24.87		
Session 1, Trial 1	29.17	19.65	3.84	.002*
Session 1, Trial 3	19.78	16.24		
Session 1, Trial 2	24.25	24.87	1.47	.164
Session 1, Trial 3	19.78	16.24		
Session 2, Trial 1	18.57	12.70	1.81	.092
Session 2, Trial 2	14.87	7.16		
Session 2, Trial 1	18.57	12.70	1.91	.076
Session 2, Trial 3	14.31	7.88		
Session 2, Trial 2	14.87	7.16	.50	.622
Session 2, Trial 3	14.31	7.88		

Table 4.8: Paired-samples t-test results for Foam Dynamic Center of Pressure Velocity.

Foam Eyes Open Center of Pressure Sway

	M	*SD*	*T*	Sig. (2-tailed)
Session 1, Trial 1	4.33	15.00	-.0656	.523
Session 1, Trial 2	4.88	15.00		
Session 1, Trial 1	4.33	15.00	.677	.510
Session 1, Trial 3	3.95	15.00		
Session 1, Trial 2	4.88	15.00	1.762	.100
Session 1, Trial 3	3.95	15.00		
Session 2, Trial 1	6.37	15.00	1.764	.100
Session 2, Trial 2	3.47	15.00		
Session 2, Trial 1	6.37	15.00	1.02	.326
Session 2, Trial 3	4.56	15.00		
Session 2, Trial 2	3.47	15.00	-1.29	.216
Session 2, Trial 3	4.56	15.00		

Table 4.9: Paired-samples t-test results for Foam Eyes Open Center of Pressure Sway.

Foam Eyes Open Center of Pressure Velocity

	M	*SD*	*t*	Sig. (2-tailed)
Session 1, Trial 1	1.99	0.27	-.416	0.683
Session 1, Trial 2	2.02	0.31		
Session 1, Trial 1	1.99	0.27	.774	0.452
Session 1, Trial 3	1.93	0.26		
Session 1, Trial 2	2.02	0.31	1.244	0.234
Session 1, Trial 3	1.93	0.26		
Session 2, Trial 1	2.06	0.53	1.584	0.136
Session 2, Trial 2	1.87	0.21		
Session 2, Trial 1	2.06	0.53	.827	0.422
Session 2, Trial 3	1.94	0.38		
Session 2, Trial 2	1.87	0.21	-.675	0.511
Session 2, Trial 3	1.94	0.38		

Table 4.10: Paired-samples t-test results for Foam Eyes Open Center of Pressure Velocity.

Foam Eyes Closed Center of Pressure Sway

	M	*SD*	*t*	Sig. (2-tailed)
Session 1, Trial 1	19.87	13.81	-.049	.962
Session 1, Trial 2	20.00	13.33		
Session 1, Trial 1	19.87	13.81	-1.3.	.216
Session 1, Trial 3	30.68	37.90		
Session 1, Trial 2	20.00	13.33	-1.19	.256
Session 1, Trial 3	30.68	37.90		
Session 2, Trial 1	17.99	11.71	1.47	.163
Session 2, Trial 2	15.43	7.81		
Session 2, Trial 1	17.99	11.71	.1.01	.295
Session 2, Trial 3	15.21	5.98		
Session 2, Trial 2	15.43	7.81	.14	.891
Session 2, Trial 3	15.21	5.98		

Table 4.11: Paired-samples t-test results for Foam Eyes Closed Center of Pressure Sway.

Firm Platform Blank Scene

Significant differences were found for the firm platform blank scene condition of the VETS performance measures between the first and second sessions, see Table 4.14.

Firm Platform Static Scene

Significant differences were found for the firm platform static scene condition of the VETS performance measures between the first and second sessions, see Table 4.15.

Foam Platform Dynamic Scene

Significant differences were found for the foam platform dynamic scene condition of the VETS performance measures between the first and second sessions, see Table 4.16.

Foam Platform Eyes Closed

Significant differences were found for the foam platform blank scene condition of the VETS performance measures between the first and second sessions, see Table 4.17.

Foam Eyes Closed Center of Pressure Velocity

	M	*SD*	*t*	Sig. (2-tailed)
Session 1, Trial 1	3.98	1.31	.185	.856
Session 1, Trial 2	3.94	1.14		
Session 1, Trial 1	3.98	1.31	.107	.916
Session 1, Trial 3	3.94	1.39		
Session 1, Trial 2	3.94	1.14	-.017	.987
Session 1, Trial 3	3.94	1.39		
Session 2, Trial 1	3.62	0.82	2.22	.043*
Session 2, Trial 2	3.37	0.70		
Session 2, Trial 1	3.62	0.82	2.99	.010*
Session 2, Trial 3	3.20	0.76		
Session 2, Trial 2	3.37	0.70	1.35	.198
Session 2, Trial 3	3.20	0.76		

Table 4.12: Paired-samples t-test results for Foam Eyes Closed Center of Pressure Velocity.

Firm Dynamic Condition				First Session		Second Session	
DV	*F*	*p*	η_p^2	M	SD	M	SD
COP Velocity First Trial	(1, 14)=6.051	0.028	0.302	2.178	0.489	2.068	0.432
COP Velocity Third Trial	(1, 14)=4.925	0.044	0.260	2.157	0.477	1.973	.317
RMS AP Third Trial	(1, 14)=4.686	0.048	0.251	0.545	0.209	0.447	0.138

Table 4.13: Significant results from repeated measure ANOVA between first and second session of the Firm Platform Dynamic Scene.

4.4.3 Velocity and Sway

In an effort to further understand the results presented in Section 4.4.2, a post-hoc repeated-measures ANOVA was performed to examine sway and velocity measures. Figures 4.4 - 4.9 show the profile plots for each sway and velocity measure. All sway measurements are in cm^2 and all velocity measurements are in cm/sec.

4.4.4 Comparison of VETS and SSQ

There are no significant findings from the collection of SSQ data.

Firm Blank Condition				First Session		Second Session	
DV	F	p	η_p^2	M	SD	M	SD
RMS AP First Trial	(1, 14)=4.740	0.047	0.253	0.573	0.277	0.505	0.249
RMS ML Third Trial	(1, 14)=5.406	0.036	0.279	0.319	0.230	0.199	0.082

Table 4.14: Significant results from repeated measure ANOVA between first and second session of the Firm Platform Blank Scene.

Firm Static Condition				First Session		Second Session	
DV	F	p	η_p^2	M	SD	M	SD
COP Sway Third Trial	(1, 14)=10.359	0.006	0.425	2.762	1.897	1.559	1.066
COP Velocity Third Trial	(1, 14)=7.668	0.015	0.354	1.793	0.243	1.681	0.229

Table 4.15: Significant results from repeated measure ANOVA between first and second session of the Firm Platform Static Scene.

Foam Dynamic Condition				First Session		Second Session	
DV	F	p	η_p^2	M	SD	M	SD
COP Sway First Trial	(1, 14)=17.833	0.001	0.560	29.173	19.649	18.574	12.703
COP Sway Third Trial	(1, 14)=4.903	0.044	0.259	19.781	16.237	14.307	7.882
COP Velocity First Trial	(1, 14)=17.296	0.001	0.553	4.848	1.365	4.041	1.184
COP Velocity Second Trial	(1, 14)=8.907	0.010	0.389	4.515	1.932	3.629	0.760
COP Velocity Third Trial	(1, 14)=11.038	0.005	0.441	3.972	1.353	3.465	0.852
RMS ML First Trial	(1, 14)=15.198	0.002	0.521	0.952	0.401	0.769	0.357
RMS AP First Trial	(1, 14)=13.568	0.002	0.492	1.179	0.346	0.976	0.210

Table 4.16: Significant results from repeated measure ANOVA between first and second session of the Foam Platform Dynamic Scene.

Foam Blank Condition				First Session		Second Session	
DV	F	p	η_p^2	M	SD	M	SD
COP Velocity Second Trial	(1, 14)=17.672	0.001	0.558	3.939	1.144	3.366	0.697
COP Velocity Thrid Trial	(1, 14)=8.461	0.011	0.377	3.944	1.386	3.201	0.764

Table 4.17: Significant results from repeated measure ANOVA between first and second session of the Foam Platform Blank Scene.

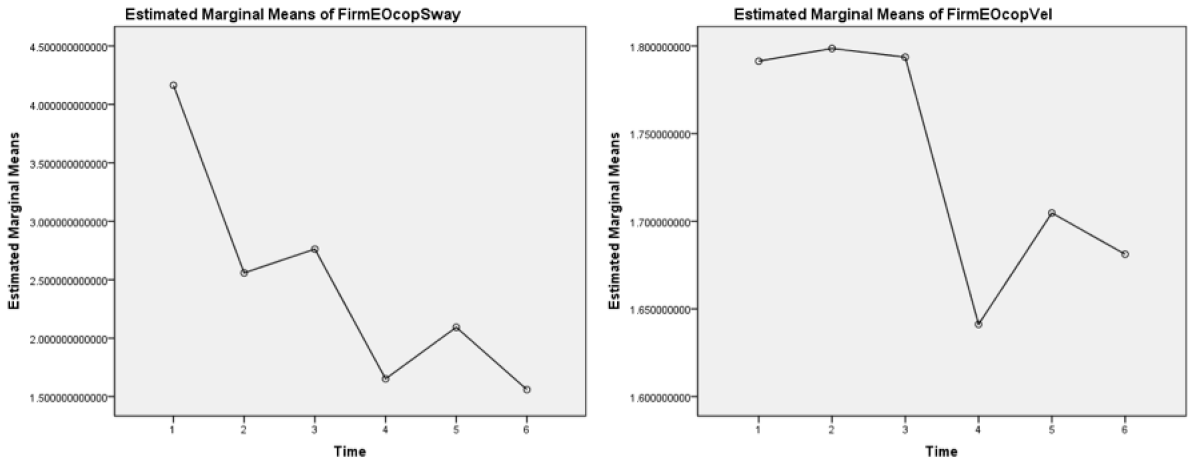

Figure 4.4: Both graphs represent the mean of measurements taken for each trial of each session in the Firm Platform Static Scene. Data points are in chronological order, the first three points were taken during the first session and the last three points were taken during the second session. The graph on the left represents Sway area in cm^2 and the graph on the right represents Velocity in cm/sec.

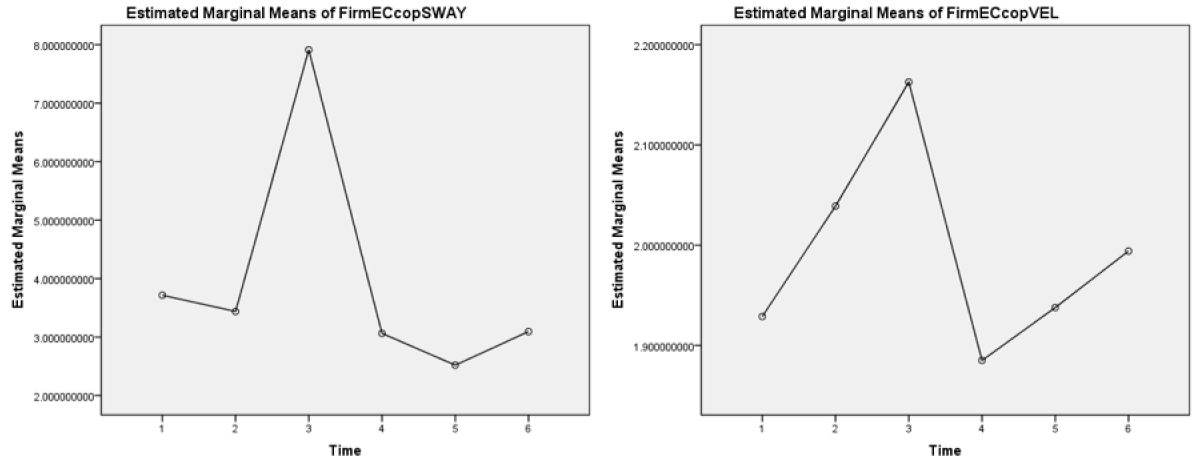

Figure 4.5: Both graphs represent the mean of measurements taken for each trial of each session in the Firm Platform Blank Scene. Data points are in chronological order, the first three points were taken during the first session and the last three points were taken during the second session. The graph on the left represents Sway area in cm^2 and the graph on the right represents Velocity in cm/sec.

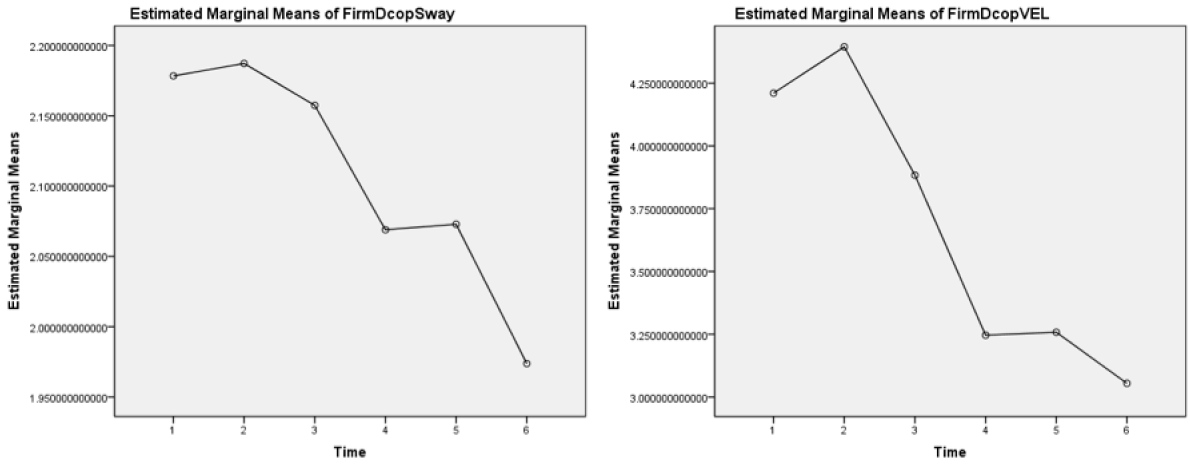

Figure 4.6: Both graphs represent the mean of measurements taken for each trial of each session in the Firm Platform Dynamic Scene. Data points are in chronological order, the first three points were taken during the first session and the last three points were taken during the second session. The graph on the left represents Sway area in cm^2 and the graph on the right represents Velocity in cm/sec.

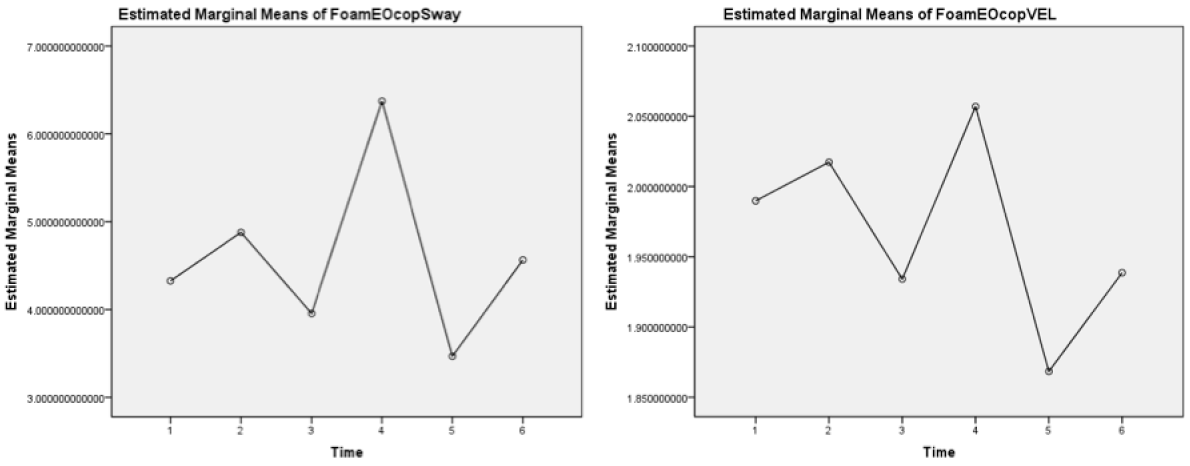

Figure 4.7: Both graphs represent the mean of measurements taken for each trial of each session in the Foam Platform Static Scene. Data points are in chronological order, the first three points were taken during the first session and the last three points were taken during the second session. The graph on the left represents Sway area in cm^2 and the graph on the right represents Velocity in cm/sec.

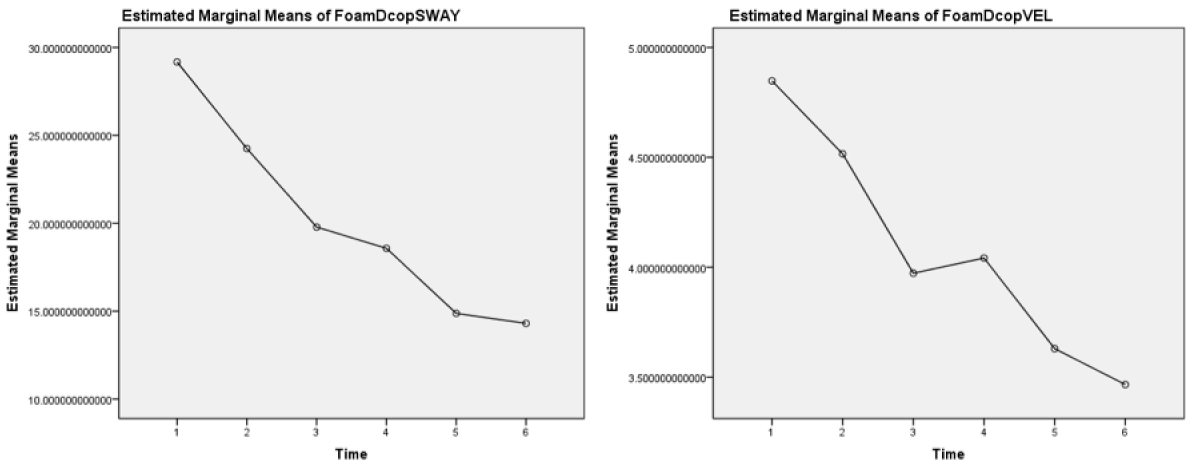

Figure 4.8: Both graphs represent the mean of measurements taken for each trial of each session in the Foam Platform Dynamic Scene. Data points are in chronological order, the first three points were taken during the first session and the last three points were taken during the second session. The graph on the left represents Sway area in cm^2 and the graph on the right represents Velocity in cm/sec.

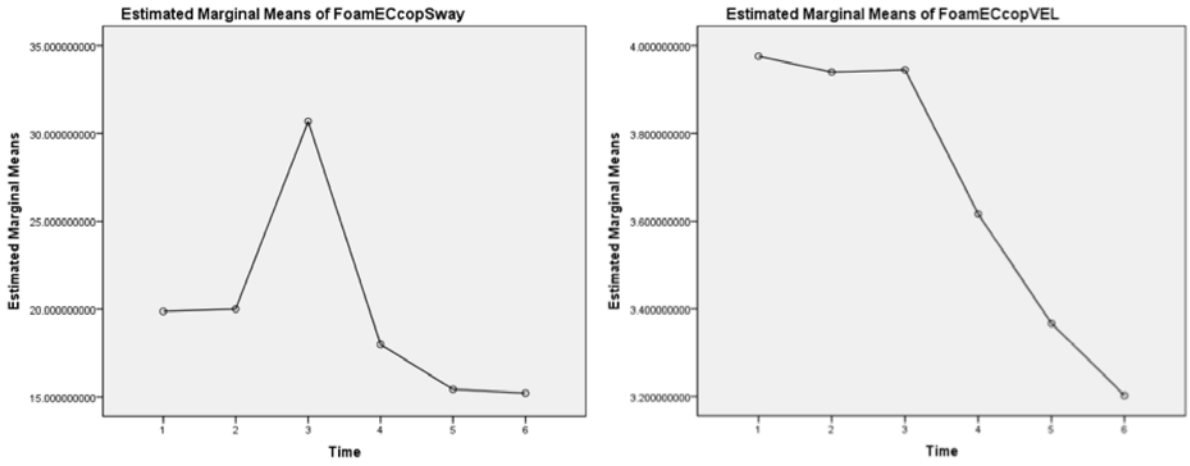

Figure 4.9: Both graphs represent the mean of measurements taken for each trial of each session in the Foam Platform Blank Scene. Data points are in chronological order, the first three points were taken during the first session and the last three points were taken during the second session. The graph on the left represents Sway area in cm^2 and the graph on the right represents Velocity in cm/sec.

THIS PAGE INTENTIONALLY LEFT BLANK

CHAPTER 5:
Discussion and Recommendations

5.1 Discussion

5.1.1 VETS

No adverse simulator sickness effects were experienced during this research. Data gathered through the use of SSQ during the course of this study suggests that the use of a VE does not adversely affect an individual's performance during or after the test.

5.1.2 VETS as a mTBI screening device for expeditionary forces

Evidence from the paired samples t-test support the use of a WBB with the VETS software suite as a reliable measure of dependent variables that assess postural control. Results from the repeated measures ANOVA support the use of VETS system to reliably measures postural control variables of interest (center of pressure sway and velocity) in a healthy military population. Where statistically significant results where noted, a trend towards better performance during the second session was noted, see Figures 4.4 - 4.9. This trend toward increased postural control during the second session could be an indicator of a practice effect experienced by subjects. If a practice effect is being seen, care should be taken when comparing multiple sessions in a healthy population to that of concussed individuals. These results contribute evidence that supports the use of the VETS system as a measure of postural control in deployed environments, which can be used as a tool to assist clinicians determine the possible presence of a TBI.

Initial results from data collection of concussed individuals, in a separate study, show a two to three fold difference in mean scores (trending toward worse balance in concussed individuals) from the healthy population scores collected in this study. This could indicate that a significant change index can be determined between healthy and concussed individuals which further supports the use of the VETS device as a tool for TBI screening.

Low cost, ease of set up and use, real-time results, and quantitative measurements are favorable factors of the VETS device for use as a tool by expeditionary forces. Components

of this system can be further reduced by using existing computers and TV screens already present in a deployed environment. The need for a dedicated computer and TV screen may not be necessary in most instances and these already present components may provide multiple uses to deployed units. About five to six VETS devices can be purchased at a cost of about three thousand dollars for the WBB, Airex foam pad, computer, and TV for the price the average clinical grade force plate on the market today. The TV component is by far the most expensive and, as stated, may already be available for use in a deployed unit.

5.2 Recommendations

5.2.1 Recommendations for Naval Leadership

The positive attributes of the VETS device warrant further support from Naval Leadership interested in arming medical providers with useful tools for the detection of a TBI. A low cost quantitative screening device for TBI is feasible with today's technology, but it requires further investigation to support its validity. Though the use of this device on ship will likely be infeasible due to an inherent unstable platform, the USN has a large presence stationed abroad at land based activities who would likely benefit from such a tool. The USMC, with medical services provided by the USN, the USA, and SOCOM would benefit most from having a screening tool such as this to use in remote deployed environments for personnel engaged in combat operations. Especially at the small unit level where robust medical capabilities may be geographically distant. The United States Air Force (USAF) could use this tool in their medical service corps and with their expeditionary personnel supporting ground operations abroad. Though significant benefit lies in the deployed realm, use of a tool such as the VETS device should not be limited to deployed personnel. Having these devices at home station clinics and hospitals might also be of great use. Advantages of such a device are not limited to Naval expeditionary forces.

5.2.2 Recommendations for Future Research

There are many opportunities for future research associated with this topic. Since the WBB is a recreational device, not a clinical grade force plate, the reliability and consistency of measurements between multiple WBB should be tested to ensure quality among devices. Potential exists in investigating the feasibility of recording baseline scores for individuals to be compared later in the event of an injury vice using healthy norms. Additionally, gather-

ing more data from a healthy population would strengthen statistical power for determining reliability of the test and provide additional data to investigate the potential practice effect noted in this study.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A:
Military Acute Concussion Evaluation

Concussion evaluation, Military Acute Concussion Evaluation, currently in use by military medical providers, from [41].

MACE

Military Acute Concussion Evaluation

Patient Name: _____

Service Member ID#: _____ Unit: _____

Date of Injury: _____ Time of Injury: _____

Examiner: _____

Date of Evaluation: _____ Time of Evaluation: _____

CONCUSSION SCREENING

Complete this section to determine if there was both an injury event AND an alteration of consciousness.

1. Description of Incident

A. Record the event as described by the service member or witness.
Use open-ended questions to get as much detail as possible.

_____

_____

_____

_____

Key questions:
- Can you tell me what you remember?
- What happened?

B. Record the type of event.
Check all that apply:

☐ Explosion/Blast ☐ Fragment ☐ Motor Vehicle Crash

☐ Blunt Object ☐ Sports Injury ☐ Gunshot Wound

☐ Fall ☐ Other _____

C. Was there a head injury event?

☐ YES ☐ NO

Key questions:
- Did your head hit any objects?
- Did any objects strike your head?
- Did you feel a blast wave? (A blast wave that is felt striking the body/head is considered a blow to the head.)

CONCUSSION SCREENING – continued

2. Alteration of Consciousness or Memory (AOC/LOC/PTA)

A. Was there Alteration of Consciousness (AOC)?
AOC is temporary confusion or "having your bell rung."

☐ YES ☐ NO

If yes, for how long? ____ minutes

Key question:
- Were you dazed, confused, or did you "see stars" immediately after the injury?

B. Was there Loss of Consciousness (LOC)?
LOC is temporarily passing out or blacking out.

☐ YES ☐ NO

If yes, for how long? ____ minutes

Key question:
- Did you pass out or black out?

C. Was there any Post Traumatic Amnesia (PTA)?
PTA is a problem remembering part or all of the injury events.

☐ YES ☐ NO

If yes, for how long? ____ minutes

Key questions:
- What is the last thing you remember before the event?
- What is the first thing you remember after the event?

D. Was there a witness?

☐ YES ☐ NO

If yes, name of witness: _____

Tips for assessment:
- Ask witness to verify AOC/LOC/PTA and estimate duration.

CONCUSSION SCREENING RESULTS (Possible Concussion?)

YES to 1C
AND
YES to 2A, 2B *or* 2C

CONTINUE the MACE:
- Complete the Cognitive, Neurological and Symptoms portions of the MACE

NO to 1C
OR
NO to 2A, 2B *and* 2C

STOP the MACE:
- Evaluate and treat any other injuries or symptoms
- Enter negative screening result into electronic medical record (V80.01)
- Communicate results with provider and line commanders
- Check for history of previous concussions and refer to Concussion Management Algorithm for appropriate rest period

COGNITIVE EXAM[a]

3. Orientation

Score 1 point for each correct response.

Ask This Question	Incorrect	Correct
"What month is this?"	0	1
"What is the date or day of the month?"	0	1
"What day of the week is it?"	0	1
"What year is it?"	0	1
"What time do you think it is?"	0	1
Correct response must be within 1 hour of actual time.		

ORIENTATION TOTAL SCORE ____/5

4. Immediate Memory

Choose one list (A-F below) and use that list for the remainder of the MACE.

Read the script for each trial and then read all 5 words. Circle the response for each word for each trial. Repeat the trial 3 times, even if the service member scores perfectly on any of the trials.

Trial 1 Script:

- "I am going to test your memory. I will read you a list of words and when I am done, repeat back to me as many words as you can remember, in any order."

Trials 2 and 3 Script:

- "I am going to repeat that list again. Repeat back to me as many words as you can remember, in any order, even if you said them before."

	Trial 1		Trial 2		Trial 3	
List F	Incorrect	Correct	Incorrect	Correct	Incorrect	Correct
Dollar	0	1	0	1	0	1
Honey	0	1	0	1	0	1
Mirror	0	1	0	1	0	1
Saddle	0	1	0	1	0	1
Anchor	0	1	0	1	0	1

IMMEDIATE MEMORY TOTAL SCORE ____/15

Immediate Memory Alternate Word Lists

List E	List D	List C	List B	List A
Jacket	Finger	Baby	Candle	Elbow
Arrow	Penny	Monkey	Paper	Apple
Pepper	Blanket	Perfume	Sugar	Carpet
Cotton	Lemon	Sunset	Sandwich	Saddle
Movie	Insect	Iron	Wagon	Bubble

NEUROLOGICAL EXAM

5. Eyes

Test pupil response to light, tracking

☐ Normal

☐ Abnormal

Tips for assessment:

- Pupils should be round, equal in size and briskly constrict to a direct, bright light.
- Both eyes should smoothly track your finger side-to-side and up and down.

6. Speech

Test speech fluency and word finding

☐ Normal

☐ Abnormal

Tips for assessment:

- Speech should be fluid and effortless – no pauses or unnatural breaks.
- Assess difficulties with word finding:
  - Does service member have trouble coming up with the name of a common object?

7. Motor

Test grip strength and pronator drift

☐ Normal

☐ Abnormal

Tips for assessment:

- Assess grip strength.
- Assess for pronator drift for 5-10 seconds by directing patient to close eyes and extend arms forward, parallel to the ground with palms up:
  - Does either palm turn inward?
  - Does either arm drift down?

8. Balance

Tandem Romberg Test

☐ Normal

☐ Abnormal

Tips for assessment:

- Have patient stand with eyes closed, one foot in front of the other heel-to-toe, arms extended forward, palms up. Observe for 5-10 seconds:
  - Does the service member stumble or shift feet?

NEUROLOGICAL EXAM RESULTS

☐ All Normal Green

☐ Any Abnormal Red

COGNITIVE EXAM[a] - Continued

9. Concentration

A. Reverse Digits

Read the script and begin the trial by reading the first string of numbers in Trial 1.

Script:

- "I am going to read you a string of numbers. When I am finished, repeat them back to me backward. That is, in reverse order of how I read them to you. For example, if I said 7 - 1 - 9, then you would say 9 - 1 - 7."

Circle the response for each string.

- If correct on string length of Trial 1, proceed to the next longer string length in the same column.
- If incorrect on string length of Trial 1, move to the same string length of Trial 2.
- If incorrect on both string lengths in Trials 1 and 2, STOP and record score as zero for that string length. Record total score as sum of previous correct trials.

List F			
Trial 1	Trial 2 (if Trial 1 is incorrect)	Incorrect	Correct
2-7-1	4-7-9	0	1
1-6-8-3	3-9-2-4	0	1
2-4-7-5-8	8-3-9-6-4	0	1
5-8-6-2-4-9	3-1-7-8-2-6	0	1

REVERSE DIGITS SCORE (9A) ____/4

Concentration Alternate Number Lists

Note: Use the same list (A-F) that was used in Question 4.

List E	
Trial 1	Trial 2
3-8-2	5-1-8
2-7-9-3	2-1-6-9
4-1-8-6-9	9-4-1-7-5
6-9-7-3-8-2	4-2-7-9-3-8

List D	
Trial 1	Trial 2
7-8-2	9-2-6
4-1-8-3	9-7-2-3
1-7-9-2-6	4-1-7-5-2
2-6-4-8-1-7	8-4-1-9-3-5

List C	
Trial 1	Trial 2
1-4-2	6-5-8
6-8-3-1	3-4-8-1
4-9-1-5-3	6-8-2-5-1
3-7-6-5-1-9	9-2-6-5-1-4

List B	
Trial 1	Trial 2
5-2-6	4-1-5
1-7-9-5	4-9-6-8
4-8-5-2-7	6-1-8-4-3
8-3-1-9-6-4	7-2-7-8-5-6

List A	
Trial 1	Trial 2
4-9-3	6-2-9
3-8-1-4	3-2-7-9
6-2-9-7-1	1-5-2-8-5
7-1-8-4-6-3	5-3-9-1-4-8

COGNITIVE EXAM[a] - Continued

9. Concentration - Continued

B. Months in Reverse Order

Script:

- "Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say: December, November…Go ahead."

Correct Response:
Dec – Nov – Oct – Sep – Aug – Jul – Jun – May – Apr – Mar – Feb – Jan

	Incorrect	Correct
ALL months in reverse order	0	1

MONTHS IN REVERSE ORDER (9B) ___/1

CONCENTRATION TOTAL SCORE ___/5
Sum of scores:
9A (0-4 points) and 9B (0 or 1 point)

10. Delayed Recall

Read the script and circle the response for each word.
Do NOT repeat the word list.

Note: Use the same list (A-F) that was used in Question 4.

Script:

- "Do you remember that list of words I read a few minutes earlier? I want you to tell me as many words from that list as you can remember. You can say them in any order."

List F	Incorrect	Correct
Dollar	0	1
Honey	0	1
Mirror	0	1
Saddle	0	1
Anchor	0	1

DELAYED RECALL TOTAL SCORE ___/5

Delayed Recall Alternate Word Lists

List E	List D	List C	List B	List A
Jacket	Finger	Baby	Candle	Elbow
Arrow	Penny	Monkey	Paper	Apple
Pepper	Blanket	Perfume	Sugar	Carpet
Cotton	Lemon	Sunset	Sandwich	Saddle
Movie	Insect	Iron	Wagon	Bubble

SYMPTOM SCREENING

11. Symptoms — Check all that apply:

- ☐ Headache
- ☐ Balance Problems
- ☐ Irritability
- ☐ Dizziness
- ☐ Nausea/Vomiting
- ☐ Visual Disturbances
- ☐ Memory Problems
- ☐ Difficulty Concentrating
- ☐ Ringing in the Ears
- ☐ Other _____

SUMMARY

Record the data for correct MACE documentation.

Cognitive Summary

Orientation Total Score - Q3	/5
Immediate Memory Total Score (all 3 trials) - Q4	/15
Concentration Total Score (Sections A and B) - Q9	/5
Delayed Recall Total Score - Q10	/5
COGNITIVE RESULTS	/30

NEUROLOGICAL RESULTS (Page 4)	☐ Normal (Green)	☐ Abnormal (Red)
SYMPTOM RESULTS	☐ No symptoms (A)	☐ 1 or more symptoms (B)

MACE RESULTS (Report all 3 parts.) Example: 24/Red/B

Abnormality in any area should be discussed with provider.

C _____ Cognitive / **N** _____ Neurological / **S** _____ Symptoms

CONCUSSION HISTORY IN PAST 12 MONTHS

12. During the past 12 months have you been diagnosed with a concussion, not counting this event?

☐ YES ☐ NO

If yes, how many? _____

Refer to Concussion Management Algorithm for clinical care guidance.

ADDITIONAL INFORMATION ABOUT MACE COGNITIVE SCORES

Although cognitive is listed first in the summary of MACE results, this should not suggest that any one of the three screening categories is more or less important than the others. Each area (Cognitive, Neurological, Symptoms) must be evaluated carefully. The results of all three evaluations must be included in any MACE report for it to be considered complete.

Regarding cognitive scores, in studies of non-concussed subjects, the mean total cognitive score was 28. Therefore, a score of < 30 does not imply that a concussion has occurred. Definitive normative data for a cut-off score are not available. The Concussion Management Algorithm stipulates that a cognitive score of < 25 or the presence of symptoms requires consultation with a provider.

Repeating the MACE cognitive exam with a different version (A-F) may be used to evaluate acute concussion recovery; however, a physical exam and symptom assessment must accompany any repeated cognitive exam. Providers should be mindful of other factors affecting the MACE cognitive score such as sleep deprivation, medications or pain.

Coding Tips for Concussion:

1. Primary code (corpsmen/medics require co-sign)
   - 850.0 – Concussion without LOC
   - 850.11 – Concussion with LOC ≤ 30 min.
2. Personal history of TBI in Global War on Terror (GWOT)
   - V15.52_2 – Injury related to GWOT, mild TBI
3. Symptom codes
   - As appropriate
4. Deployment status code
   - V70.5_5 – During deployment encounter
5. Screening code
   - V80.01 – Special screening for TBI code
6. E-code (external cause of injury)
   - E979.2 (if applicable) – Terrorism involving explosions and fragments

References

a. McCrea, M. Standardized Mental Status Testing on the Sideline After Sport-Related Concussion. J Athl Train. 2001 Sep;36(3):274-279.

For additional copies or information call 1.866.966.1020 or email info@DVBIC.org

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B:
Institutional Review Board Approval

Naval Postgraduate School
Human Research Protection Program

From: President, Naval Postgraduate School (NPS)
To: LT Lee Sciarini, USN
Dr. Joe Sullivan
Maj Casey DeMunck, USMC
Via: Chairman, Institutional Review Board (IRB)

Subj: BASELINE ESTABLISHMENT USING VIRTUAL ENVIRONMENT TBI SCREENING (VETS)

Encl: (1) Approved IRB Initial Review Protocol

1. The NPS IRB is pleased to inform you that the NPS President has approved your initial review protocol (NPS IRB# NPS.2015.0030-IR-EP7-A). The approved IRB Protocol is found in enclosure (1). Completion of the CITI Research Ethics Training has been confirmed.

2. This approval expires on 30 June 2015. If additional time is required to complete the research, a continuing review report must be approved by the IRB and NPS President prior to the expiration of approval. At expiration all research (subject recruitment, data collection, analysis of data containing PII) must cease.

3. You are required to obtain documented consent according to the attached approved consent procedure.

4. You are required to report to the IRB any unanticipated problems or serious adverse events to the NPS IRB within 24 hours of the occurrence.

5. Any proposed changes in IRB approved research must be reviewed and approved by the NPS IRB and NPS President prior to implementation except where necessary to eliminate apparent immediate hazards to research participants and subjects.

6. As the Principal Investigator (PI) it is your responsibility to ensure that the research and the actions of all project personnel involved in conducting this study will conform with the IRB approved protocol and IRB requirements/policies.

Subj: BASELINE ESTABLISHMENT USING VIRTUAL ENVIRONMENT TBI SCREENING (VETS)

7. At completion of the research, no later than expiration of approval, the PI will close the protocol by submitting an End of Experiment Report.

Lawrence G. Shattuck, PhD
Chair
Institutional Review Board

Ronald A. Route
Vice Admiral, U.S. Navy (Ret.)
President, Naval Postgraduate School

Date: 3-12-2015

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C:
Recruitment Flyer

Test Your Balance for TBI Research

Volunteers Needed to Help Traumatic Brain Injury (TBI) Research

Come take part in a study that aims to use balance as a screening tool for concussion/TBI. Results from this study will benefit TBI research for developing simple tools to test for concussion in deployed environments.

No experience with a Wii Balance Board or with Virtual Environments is needed. During this study, you will be asked to stand on a Wii Balance Board while viewing a VE on a large screen television. Various scenes will be presented, each lasting 30 seconds with a short rest time in between. You will also be asked to fill out a short demographics survey and simulator sickness questionnaire. The purpose of this study is to demonstrate the validity and reliability of a portable, deployable system that can be used to assist with assessment of concussion in austere environments. Specifically, the VETS device will be utilized to collect baseline balance data on a healthy military population.

WHO: U.S. Military personnel.
WHERE: Watkins 212A
HOW LONG: Approximately 30 mins.
WHEN: During normal school hours.
HOW: Contact Casey DeMunck at cgdemunc@nps.edu to schedule.

Risks associated with this study are negligible. Your participation is completely voluntary and confidential. The principal investigator for this study is LT Lee Sciarini (lwsciari@nps.edu). Please contact the NPS IRB Chair Dr. Larry Shattuck (lgshattu@nps.edu) with any questions regarding your rights as a participant.

APPENDIX D:
Simulator Sickness Questionnaire

No_____ Date_____

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Last version : March 2013

***Original version : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*(3), 203-220.

APPENDIX E:
Demographics Survey

Virtual Environment Traumatic Brain Injury Screen (VETS) Study
Demographic Survey

Subject#: Date:

Please provide the following information. You may use the back of this page or request additional paper if needed.

1. Age: _____

2. Gender: Male ____ Female ____

3. What is your preferred hand for writing? Right ____ Left ____

4. Do you serve or have you served in any armed forces? Yes ____ No ____

4a. If yes, Branch: _____ Rank: _____ Years: _____

5. What is your rating/MOS/career field? For example: Surface Warfare Officer, pilot, infantry officer, etc.

5a. MOS/rating (0402, 1802, 3002, etc): _____

5b. In plain English (Pilot, Yeoman, Armor, etc) _____

6. Have you been deployed overseas? (May include non-combat deployments)

Yes ____ No ____

6a. If YES, date of return from most recent deployment: _____

6b. Location of most recent deployment: _____

6c. Main responsibilities during most recent deployment: _____

7. Have you been diagnosed with a concussion/TBI? Yes____ No____

7a. If so, approximately how long ago: _____

List of References

[1] H. R. Champion, "A profile of combat injury," *The Journal of Trauma Injury, Infection, and Critical Care*, vol. 54, no. 5, pp. 1–2, December 2002.

[2] K. H. Taber, D. L. Warden, and R. A. Hurley, "Blast-related traumatic brain injury: What is known?" *Journal of Neuropsychiatry Clinical Neuroscience*, vol. 18, no. 2, pp. 141–145, Spring 2006.

[3] K. H. Taber and R. A. Hurley, "OEF/OIF deployment-related traumatic brain injury," *PTSD Research Quarterly*, vol. 21, no. 1, pp. 1–3, 2010.

[4] E. Conaton, "DoD policy guidance for management of mild traumatic brain injury/concussion in the deployed setting," *Washington, DC: Department of Defense*, September 2012.

[5] G. K. Anderson, "Psychological health and traumatic brain injury," *Military Medicine, International Journal of AMSUS*, vol. 177, no. 8, August 2012.

[6] Brain Injury Association of America, "Mild brain injury and concussion," 2015. [Online]. Available: http://www.biausa.org/mild-brain-injury.htm

[7] D. C. of Excellence, "Portable field-based devices for the early diagnosis of mild traumatic brain injury," Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury, September 2010.

[8] F. Haran, R. Tierney, W. Wright, E. Keshner, and M. Silter, "Acute changes in postural control after soccer heading," *International Journal of Sports Medicine*, vol. 34, no. 4, pp. 350–354, 2013.

[9] W. Wright, J. McDevitt, R. Tierney, M. Dumont, A. Dumont, and K. Appiah-Kubi, "Virtual environment TBI screen (VETS)," October 2014.

[10] G. Wright, "VETS protocol," November 2014.

[11] Office of the Deputy Assistant Secretary of Defense, "2013 demographic profile of the military community," Department of Defense, Report, 2013.

[12] "Operation of the Defense Acquisition System," Department of Defense Instruction, January 2015.

[13] L. J. Carroll, J. D. Cassidy, L. Holm, J. Kraus, and V. G. Coronado, "Methodological issues and research recommendations for mild traumatic brain injury: the who collaborating centre task force on mild traumatic brain injury," *Journal of Rehabilitation Medicine*, vol. 43, pp. 113–125, 2004.

[14] National Institute of Justice, "Ballistic resistance of body armor NIJ standard-0101.06," U.S. Department of Justice, Report, 2006.

[15] W. Moss, M. King, and E. Blackman, "Skull flexure from blastwaves: A mechanism for brain injury with implications for helmet design," *Physical Review Letters*, vol. 103, pp. 1–4, 2009.

[16] Gentex, "USMC lightweight ballistic protective helmet," Product Information Sheet.

[17] Joint IED Defeat Organization, "About JIEDDO." [Online]. Available: https://www.jieddo.mil/about.aspx

[18] G. England, "Joint improvised explosive device defeat organization (JIEDDO)," Department of Defense Directive, February 2006.

[19] C. D. Gideons, F. M. Padilla, and C. R. Lethin, "Combat hunter," *Marine Corps Gazette*, vol. 92, no. 9, pp. 79–84, September 2008.

[20] K. A. Schwab, B. Ivins, G. Cramer, W. Johnson, M. Sluss-Tiller, K. Kiley, W. Lux, and D. Warden, "Screening for traumatic brain injury in troops returning from deployment in afghanistan and iraq: Initial investigation of the usefulness of a short screening tool for traumatic brain injury," *Journal of Head Trauma Rehabilitation*, vol. 22, no. 6, pp. 377–389, 2007.

[21] M. R. Gill, D. G. Reiley, and S. M. Green, "Interrater reliability of glasgow coma scale scores in the emergency department," *Annals of Emergency Medicine*, vol. 42, no. 2, pp. 215–223, February 2004.

[22] J. Borg, L. Holm, J. D. Cassidy, P. Peloso, L. Carroll, H. Von Holst, and K. Ericson, "Diagnostic procedures in mild traumatic brain injury: results of the WHO collaborating centre task force on mild traumatic brain injury," *Journal of Rehabilitation Medicine*, vol. 36, pp. 61–75, 2004.

[23] C. Eierud, R. C. Craddock, S. Fletcher, M. Aulakh, B. King-Casas, D. Kuehl, and S. M. LaConte, "Neuroimaging after mild traumatic brain injury: Review and meta-analysis," *NeuroImage: Clinical*, vol. 4, pp. 283–294, January 2014.

[24] G. Barkhoudarian, D. A. Hovda, and C. C. Giza, "The molecular pathophysiology of concussive brain injury," *Clinical Sports Medicine*, vol. 30, no. 1, pp. 33–48, 2011.

[25] J. Furman, "Posturography: uses and limitations," *Bailliere's clinical neurology*, vol. 3, no. 3, pp. 501–513, November 1994.

[26] J. R. Basford, L. S. Chou, K. R. Kaufman, R. H. Brey, A. Walker, J. F. Malec, A. M. Moessner, and A. W. Brown, "An assessment of gait and balance deficits after traumatic brain injury," *American Academy of Physical Medicine and Rehabilitation*, vol. 84, no. 3, pp. 343–349, March 2003.

[27] Biodex Medical Systems, Inc., "Why the clinical test for sensory integration of balance (CTSIB) for concussion baseline balance testing?"

[28] A. Ruhe, R. Fejer, and B. Walker, "The test-retest reliability of centre of pressure measures in bipedal static task conditions-a systematic review of the literature," *Gait & posture*, vol. 32, no. 4, pp. 436–445, 2010.

[29] D. Lafond, H. Corriveau, R. Hébert, and F. Prince, "Intrasession reliability of center of pressure measures of postural steadiness in healthy elderly people," *Archives of physical medicine and rehabilitation*, vol. 85, no. 6, pp. 896–901, 2004.

[30] D. Lin, H. Seol, M. A. Nussbaum, and M. L. Madigan, "Reliability of COP-based postural sway measures and age-related differences," *Gait & posture*, vol. 28, no. 2, pp. 337–342, 2008.

[31] K. R. Kaufman, R. H. Brey, L.-S. Chou, A. Rabatin, A. W. Brown, and J. R. Basford, "Comparison of subjective and objective measurements of balance disorders following traumatic brain injury," *Medical Engineering & Physics*, vol. 28, no. 3, pp. 234–239, 2006.

[32] J. T. Finnoff, V. J. Peterson, J. H. Hollman, and J. Smith, "Intrarater and interrater reliability of the balance error scoring system (BESS)," *Physical Medicine and Rehabilitation*, vol. 1, no. 1, pp. 50–54, January 2009.

[33] "The glasgow structured approach to assessment of the glasgow coma scale," 2014. [Online]. Available: http://www.glasgowcomascale.org/

[34] L. French, M. McCrea, and M. Baggett, "The military acute concussion evaluation (MACE)," *Journal of Special Operations Medicine*, vol. 8, no. 1, pp. 68–70, Winter 2008.

[35] R. L. Coldren, M. P. Kelly, R. V. Parish, M. Dretsch, and M. L. Russell, "Evaluation of the military acute concussion evaluation for use in combat operations more than 12 hours after injury," *Military medicine*, vol. 175, no. 7, pp. 477–481, July 2010.

[36] J. Difede, J. Cukor, N. Jayasinghe, I. Patt, S. Jedel, L. Spielman, C. Giosan, and H. G. Hoffman, "Virtual reality exposure therapy for the treatment of posttraumatic stress disorder following september 11, 2001." *Journal of Clinical Psychiatry*, vol. 68, no. 11, pp. 1639–1647, 2007.

[37] L. F. Hodges, R. Kooper, T. C. Meyer, B. O. Rothbaum, D. Opdyke, J. J. De Graaff, J. S. Williford, and M. M. North, "Virtual environments for treating the fear of heights," *Computer*, vol. 28, no. 7, pp. 27–34, 1995.

[38] A. Rizzo, J. G. Buckwalter, C. van der Zaag, U. Neumann, M. Thiébaux, C. Chua, A. van Rooyen, L. Humphrey, P. Larson *et al.*, "Virtual environment applications in clinical neuropsychology," *Proceedings IEEE Virtual Reality, 2000*, pp. 63–70, 2000.

[39] P. McGeorge, L. H. Phillips, J. R. Crawford, S. E. Garden, S. Della Sala, A. B. Milne, S. Hamilton, and J. S. Callender, "Using virtual environments in the assessment of executive dysfunction," *Presence: Teleoperators and Virtual Environments*, vol. 10, no. 4, pp. 375–383, 2001.

[40] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, "Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness," *The International Journal of Aviation Psychology*, vol. 3, no. 3, pp. 203–220, November 1993.

[41] Defense and Veterans Brain Injury Center, "Military acute concussion evaluation," February 2012.

Initial Distribution List

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California